Managing Red Pine Plantations

Ontario

Ministry of Natural Resources

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Minister

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PREFACE

Ever since the start of reforestation in southern Ontario, forest managers have studied and learned more about red pine than any other tree species. Many measurements, thinning trials and experiments have been carried out. A number of good publications have been produced and management knowledge is available in a number of forms. Much practical expertise on red pine management also resides in the minds of management foresters and technicians. This publication collates our knowledge and information to provide a factual reference that the forest manager can consult when making work plans, on-the-ground management evaluations and decisions regarding red pine plantations.

Whenever foresters discuss red pine, two names are usually referenced. Al Beckwith (OMNR) and Will Stiell (CFS). Both these researchers have contributed to the understanding of how red pine performs with regard to growth and yield. Their work remains a major contribution here.

Important new site information is being released in this publication. Findings by Ted Taylor (Ontario Institute of Pedology) and G. Pierpoint (OMNR) tell the forest manager how to determine the best species to site selection using soils information.

With so much practical technical information packaged under one cover, foresters will continue to find this guide a handy reference for years to come.

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INTRODUCTION

For some seventy years, professional foresters have been managing red pine plantations in Ontario. Around the turn of this century, the government of the day recognized the need for re-establishing tree cover on large areas of sand plains in southern Ontario. Here, the original pine and mixedwood forests have been removed, and farming attempted, then abandoned. The first provincial forester, Dr. E. J. Zavitz, led the way in reforesting and rehabilitating these large "wastelands" which were a financial burden, particularly to the counties of Norfolk, Simcoe, York, Durham, Renfrew, Bruce, Prescott and Russell. Our province owes much to Dr. Zavitz and other far-sighted leaders in reforestation such as William Saunders, Ferdinand Larose, I. C. Marritt and Premier E. C. Dury.

The principal management objective for the first 30 years or so was the rehabilitation and consolidation of the blowsand areas. This in turn helped regulate the water table and stream flow and improve local microclimates. Of course, the early foresters and their peers realized that a timber crop could be harvested later from these plantations, which also would benefit the farm community and local industry. This main objective of reclamation through reforestation was accomplished by the late 1930s. Since red pine grew well on most of these sandy sites and was resistant to many diseases, insects and drought, this species was favoured for planting, although white and Scots pines were sometimes used in combination with the red pine. Today these plantations, some of which have now reached age 65, are important wood producers and provide considerable environmental and wildlife habitat values. Their worth increases as each year passes.

Management objectives for the next several decades are varied. There are still thousands of hectares of cleared land that need reforesting, particularly in central and eastern Ontario. These areas, along with the maturing existing plantations that will ultimately be cut, require new planting programs and early tending operations. Some existing red pine plantations are serving as a "nurse crop" for a developing understory of hardwood species. Such a stand conversion should be encouraged where the soil is suitable for good hardwood growth. Other conversions, such as to white pine, may also be justified in certain locations. Nevertheless, a major objective will always be the production of red pine poles and sawlogs, with secondary products such as pulpwood, pallet material, and posts achieved during thinning. Under the integrated resource management policy for southern Ontario, further objectives are to improve recreational and aesthetic values, and to provide wildlife habitat and environmental protection.

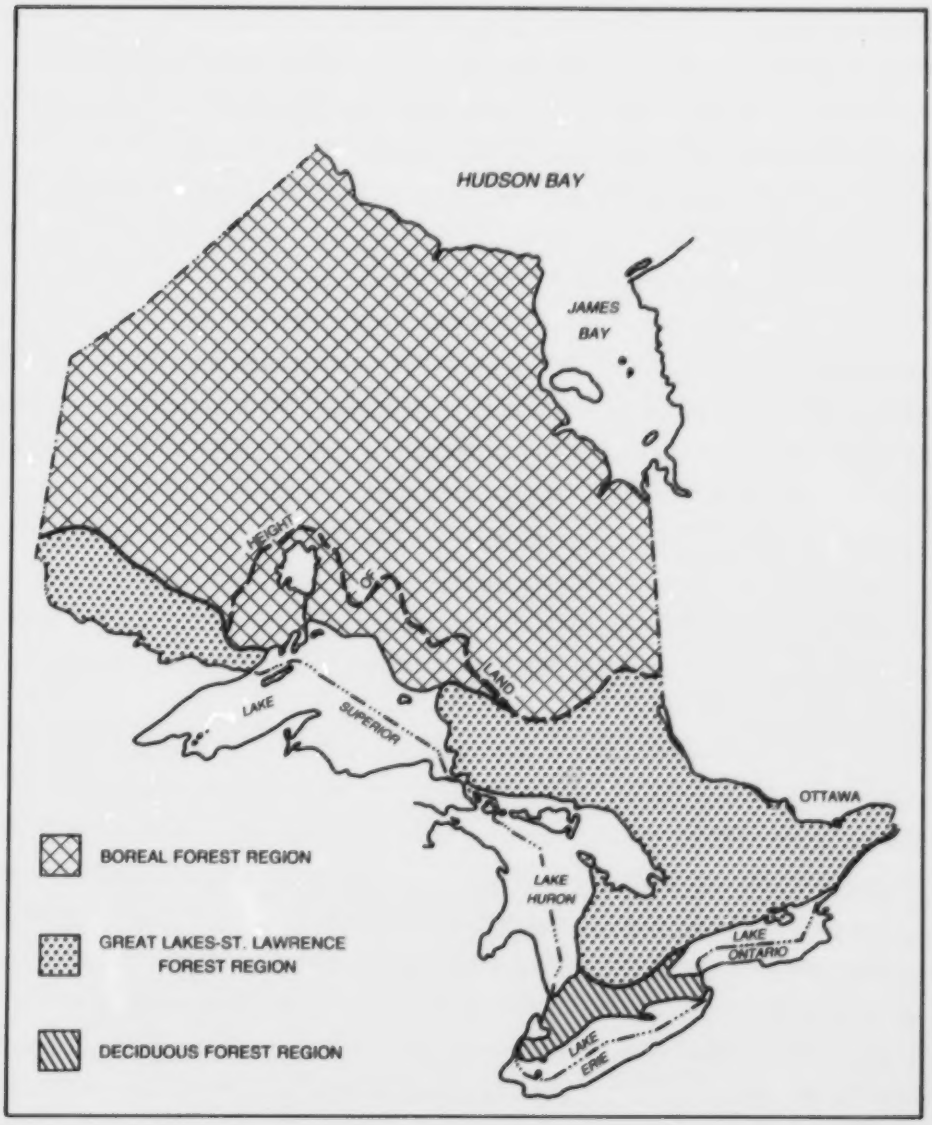


Figure 1. *Ontario forest regions: The commercial range of red pine extends throughout the Great Lakes – St. Lawrence Forest Region in Ontario.*

I. SILVICS OF RED PINE

Red pine (*Pinus resinosa* Ait.) occurs characteristically in even-aged, often pure stands. It establishes itself readily, particularly where fire or some other radical disturbance has prepared the site. Moreover, it is an ideal plantation species, capable of perhaps the highest yield of any Ontario forest tree, up to about age 70. As with all species, red pine has its own particular site requirements and growth characteristics, and unless these are understood and taken into account its full potential will not be realized.

Range

The natural range of red pine in Canada extends from southeast Manitoba to Newfoundland. The species occurs widely in the Great Lakes— St. Lawrence and Acadian Forest Regions, has scattered representation in the southern Boreal Forest Region, and just enters the northern portion of the Deciduous Forest Region. The original distribution of red pine has been much modified by logging, fire and settlement. Its distribution has been extended successfully by planting where the soil and local climate are favourable.

In eastern Ontario, the natural range of red pine extends up to Lake Abitibi, and thence its northern boundary tends west and slightly north, passing just to the north of Lake Nipigon and reaching about 52° N latitude in Forest Section B.22a.[1] From there it extends southwest to the Manitoba border and to the north of Lake of the Woods. Red pine does not occur naturally in the Niagara peninsula and its southern limit approximates a line between the southern tip of Lake Huron and the western end of Lake Ontario. The commercial range of red pine in Ontario coincides with the Great Lakes–St. Lawrence Forest Region. (Fig. 1).

Taxonomy and Genetics

Red pine belongs to the subgenus *Diploxylon*, in which the needles have two vascular bundles, and it is the only Canadian representative of the subsection *Sylvestres*. Probabably the most closely related species is Austrian pine (*P. nigra* Arnold). No varieties of red pine have been described to date. The species is morphologically very uniform.

While natural variation of different traits including growth rates, survival, photoperiodic response and wood quality, has been found between provenances, the pattern is often obscure and difficult to relate to climatic data. The 10-year results of comprehensive provenance trials with red pine, throughout eastern and central Canada, have shown differences in height growth at

1. J.S. Rowe, Forest Regions of Canada, Ottawa, 1972.

individual test sites. Promising seed sources were thus indicated, and while the trials did not identify any consistently good performers, some consistently poor ones did emerge. Three of these poor performers were the pine from Stanley, Nova Scotia; Grand Lake, New Brunswick and Kenogami, Quebec. Pending specific information on the performance of other provenances in a particular area, any stock planted should be derived from the seed collection zone in which the planting area is located. There is also variation between progeny from individual trees.

The possibility of inducing genetic variation by hybridization is minimal, since attempts to cross red pine with other species have been virtually without success. Best expectations for tree improvement programs seem to point to making only small genetic gains. The cost of such programs may not be economically justifiable.

Environmental Factors

CLIMATE

The large geographic range of red pine embraces considerable climatic diversity. In southern Ontario its habitats are characterized by warm to dry conditions, and in the central part of its range by moderate temperatures (annual average daily mean 4.4°C) and low precipitation (77 cm), with warm and dry summers. Cold climate conditions appear to restrict development in the north where its distribution is related to the length of the frost-free period.

Local climate can both extend or restrict the area of survival in particular situations, and should be taken into account in planting programs. Thus warmer and drier sites permit intrusion of red pine north into the Boreal Forest. On the other hand, frost-prone areas with unseasonable freezing temperatures can seriously damage or kill newly flushed growth. Such areas include depressions or breaks in natural slopes where free air drainage is impeded, or on dry sand flats where radiation allows rapid cooling, and particularly if there is a lack of tree cover which reduces heat losses. These areas should be avoided when planting. Fail spots in red pine plantations caused by frost-pocket conditions are usually characterized by a particular vegetation type composed of sweet-fern (*Comptonia peregrina* (L.) Coult.), stunted blueberries (*Vaccinium spp.*), sedges and grasses. Bracken fern (*Pteridium aquilinum* (L.) Kuhn) is frost sensitive, and unseasonal browning of its foliage can help the forest manager identify frost-prone sites.

Extremely high temperatures can develop at the ground surface (insolation) on exposed sites and are very damaging to young seedlings. Fire-blackened surfaces are particularly hazardous in this respect.

FIRE

Naturally occurring surface fires are a hazard to contend with on the drier sites where red pine is normally found. Such fires were important in the regeneration of this species with its stringent

seedbed seedling-environment requirements; that is, only fire could provide these requirements in the natural state. In addition, mature stands with their thick insulating bark and elevated crowns are able to withstand surface fires of gentle to moderate intensity.

However, the normal balance that promoted natural pine regeneration after a fire in a good seed year was upset by past logging and clearing. The fires associated with these activities recurred so frequently that the young, vulnerable pine stands were destroyed before reaching seed-bearing age. Thus pine trees were frequently eliminated. Plantations of red pine are similarly vulnerable to fire. The protection aspects of fire are described in Section IV.

LIGHT

Red pine cannot grow satifactorily under even moderate overhead cover, although seedlings can make good height growth in as little as 45 percent of full light up to age five. After this age full light is required for maximum growth. Leader diameter and weight of roots, wood and foliage all increase markedly in full light.

Seedlings that germinate under dense shade rarely persist for 10 years. Hence, underplanting a residual forest stand with red pine should be avoided unless early release is planned.

OTHER VEGETATION

There are influences other than shade which can inhibit maximum red pine growth. The success of red pine regeneration depends to a large degree on the adverse effects of competing vegetation. A heavy cover of heath plants such as blueberries and sweet-fern in red pine plantations has been estimated to utilize large quantities of water, and drastically reduce wood yields. In some red pine plantations, trees growing in dense sweet-fern competition show stunted height growth, yellowish foliage, crooked stems and dead shoots.

Black walnut (*Juglans nigra* L.) is known to secrete juglone from its roots which is toxic to some plant species. Mortality, needle loss and discoloration of red pine interplanted with walnut in southern Ontario have been reported.

SOIL

Red pine, while not demanding in terms of soil moisture or nutrient supply, does have specific site requirements which are detailed in Section II.

Seeds and Seedlings

FLOWERING AND CONE DEVELOPMENT

Red pine is monoecious with both male and female flowers occurring on the same tree, although they are usually located on separate branches and in different portions of the crown. Female

flowers occur singly or in clusters at or near the tips of emerging shoots in the upper portions of the crown. Male flowers occur in clusters at the base of emerging shoots in the mid to lower portions of the crown. When young, red pine trees produce female flowers for a few years before male flowers are produced.

Flowers of both sexes emerge from mid-May to early June, prior to flushing of vegetative buds. Pollination occurs for approximately one week in late May or early June after which the female flowers close up and develop into small green conelets. Female flowers that are insufficiently pollinated will abort within a few weeks of pollination and normally drop off the tree.

Conelets continue to develop throughout the summer but in September they enter into a resting phase which lasts throughout the winter. In the spring of the following year, growth resumes and cones undergo considerable enlargement. Cones reach their final size by early July and ripening occurs from mid-August to mid-September.

Seed maturation is complete by early September. Cones start to open soon after seed is mature with 70 percent of the seed dispersing between mid-September and October. However, if weather conditions are cool and wet in the fall, the bulk of the seedfall can be deferred until spring or as late as August the following year.

CONE CROPS

While cones with viable seed have been produced by 12-year-old planted red pine, the production of appreciable seed crops does not occur until trees reach full maturity. Seed production is usually best from 50 to 150 years of age. Good seed crops occur on an average of every three to seven years with some seed produced in the intervening years (Table 1).

In red pine, less than half of the scales on a typical cone produce viable seed. Ovules are borne on the scales and are located next to the central axis of the cone. During pollination their numbers range from 30 to 110 depending on cone length, number of cone scales, and position of the cones in crown. However, abortion of ovules normally reduces the actual number of viable seed produced by 50 to 60 percent. A typical red pine cone usually yields 15 to 50 seeds. Cones produced in the upper third of the crown and on main branch terminals at each crown level, produce the greatest number of viable seed per cone.

The size of the cone is strongly affected by stand density. Trees growing under open conditions develop larger crowns and hence yield more cones per tree. Dense stands with short-crowned trees are poor cone producers. In an 18-year-old red pine plantation, established as a spacing trial, data were collected on cone yields at the time of the first heavy cone crop. Spacing intervals ranged from 1.2 m x 1.2 m to 6.4 m x 6.4 m. Maximum yields of 340 cones per tree (79823 cones per hectare) were recorded for trees established at the widest spacing. Trees planted at this spacing had full crowns and, for their age, produced maximum cone crops.

Thinning of red pine plantations has been shown to greatly increase cone production. For typical seed production areas it has been recommended that an average spacing equivalent to

Table 1: Flowering, Cone and Seed Data for red pine

Seed-bearing age	
– mininum	20 to 25 a
– optimum	50 to 150 a
Crop intervals	3 to 7 a
Flowering time	May to June
Cone ripening	mid-September to October
Characteristics of ripe cones	
– colour	deep purple with reddish brown scale tips
– specific gravity	0.80 to 0.94
– will float in	kerosene
Collection dates	
– earliest	September 10
– latest	October 16
Seed dispersal	fall to spring
Cone yield	0.5 hL/tree
Closed cones	3575/hL to 4950/hL
Average Viable seed	122 000/kg
Germinative energy (percentage of seed germinated at peak of germination trend)	69% in 10 d
Safe storage conditions (dry, sealed)	
– moisture content (dry weight)	5% to 8%
– temperature	1°C to 3°C
– possible duration	30 a

half the average height of dominant and co-dominant trees should be maintained by periodic thinning. Thinning for seed production gives best responses when applied to young stands on good sites.

Within the stand, crown position or relative diameter class is important to cone production. This size of the crop tends to increase with tree size although variability within diameter classes is large. Some red pine are said to be consistently good or consistently poor cone producers. In seed production areas, periodic observations should be made to identify unproductive trees for removal.

Nutrition is a key factor influencing flower and cone production. Studies have shown that trees occurring on nutrient-rich sites produce better cone crops than those occurring on poor sites. A number of studies have shown that chemical fertilizers are able to stimulate flower production in some conifer species. However, the success of fertilizer application in the stimulation of flowering in conifers is highly dependent on the soil characteristics, weather conditions, the time and rate of application, and the balance between nutrients in the fertilizer mix. More testing is required before fertilizers can be used as a practical technique for consistent and ensured stimulation of flower and cone production in red pine plantations.

SEED YIELD

Potential seed production can be diminished by a number of non-physiological factors. Cone and seed insects can reduce seed crops by 40 to 100 percent in open-grown red pine stands. Unfavourable weather during flowering and the pollination period, as well as depredation by squirrels, are other factors which reduce the amount of collectable seed.

Yields in excess of two million viable red pine seed per hectare have been estimated; "average" yields would of course be much lower, but it is difficult to set a figure for them. For seed production areas it has been suggested that 600 trees on 12 hectares are necessary to yield one million plantable seedlings per year.

Red pine seed has an average germinative capacity of greater than 75 percent, and if properly sealed and stored under dry cold conditions can maintain high viability for up to 30 years (Table 1).

Seedling Establishment

Cones open best on warm autumn days. Seeds are dispersed naturally to a distance generally no greater than the height of the tree, although dispersal distance will be greater if seeds are windborne. Prior to germination, seeds may be eaten by birds, insects, squirrels, chipmunks, voles and mice.

In general, the factors of major importance to seedbeds are soil conditions, temperature and vegetative cover. The soil must be moist near the surface during the germination period; this is more likely on sites with finer textured soil and those with northern exposures. Red pine seeds have no dormancy requirements, and germination of naturally shed seeds usually occurs at temperatures of above 16°C in late spring to early summer when moisture and seedbed conditions are favourable. Seedlings become established only in partly shaded places where grass and litter are not thick or where mineral soil is exposed.

Following germination, young seedlings are highly vulnerable to climatic and biotic hazards. Prominent threats are drought, freezing or high temperatures, flooding, rodents, root competition, shade and smothering by tall grasses or hardwood leaves.

General Development

Red pine seedlings make rapid early growth on favourable sites, in the absence of overhead cover, and reach breast height in four to six years. Maximum heights in old-growth stands were reported to be about 46 metres. Today 25 metres is not unusual for mature second-growth trees.

Similarly, a maximum diameter at breast height of 152 centimetres has been cited, but dbh of mature red pine is now commonly in the range of 30 to 60 centimetres.

Maximum age is around 350 years, but under management rotations ages range from 80 to 110 years.

Morphology

NEEDLES

Red pine seedlings have six to nine cotyledons, without serrations. Normal leaves, produced after the first year, are borne in bundles of two, with a persistent sheath at the base, and are 10.2 to 16.5 centimetres long. New leaves begin their development in the spring, complete it by late summer and make no further growth in subsequent years. The majority of needles persist for three years, but some are retained for six.

SHOOTS

The length of a terminal shoot is determined the preceding summer by the number of stem units (needle internodes) laid down in the winter bud. The shoot develops the following spring by elongation of the stem units; the more there are the greater the potential length. Environmental conditions at the time of stem unit initiation affect the number of units formed, i.e. irrigation can increase them. How well the growth potential is realized depends on the availability of soil moisture the following spring. Water stress can limit the elongation of stem units. The importance of appropriate watering schedules in the nursery in relation to optimum development of the planting stock, is evident.

Normally only one annual whorl of branches develops from lateral buds formed at the end of the leading shoot. Occasionally a second flush produces lammas shoot in late summer – likely caused by rain followed by a dry spell, and presumably resulting in early elongation of the stem units.

CROWNS

Red pine crowns are dense and symmetrical, generally ovoid in shape with upcurved branches. Within the crown, foliage weight increases from the top downward for the first few whorls, remains constant for several more, and then diminishes towards the crown base. The mean weight is found at or slightly below the midpoint of the crown.

Crowns enlarge by the annual extension of the main stem and branches. In relatively open-grown trees, the rate of branch extension diminishes with age, similarly to height growth, with the effect most marked at 45 years and upwards. For stand-grown trees, the crowns expand until the canopy closes. The lower branches then die from mutual shading and the crown width is limited by whipping abrasion. Stand density, which contributes to shading, is a critical factor in controlling the length and thickness of branches and the amount of foliage they bear.

Following closure, the crown size of individual trees tends to stabilize. Foliage weight per unit area is higher at closer spacings, at least until canopy closure, after which it may fluctuate in the approximate range of 18500 to 25000 kilograms per hectare (ovendry basis).

As a rule, stemwood increment increases with descent from the apex, and reaches a maximum near the live crown base or the point of greatest branch development. There is evidence that within the live crown, growth of a stem internode is mainly influenced by the foliage in the whorl immediately above it. One-year old leaves seem to be the most productive. In a closed stand, the lowest living branches are little if at all productive, owing to sparse foliage and low light levels. Pruning the lower 45 percent of the live crown in dominant trees causes little reduction in stem diameter growth, and growth rates soon recover following this operation.

ROOTS

Most root elongation takes place during two periods of growth activity; one in spring and early summer, the other in early fall, with an intervening decline during summer. The pattern is apparently inherent, but prevailing soil moisture and temperature conditions can influence the timing and intensity of growth activity.

Root systems tend to be widespreading and moderately deep, subject to modification by soil conditions. In early years, a taproot and numerous branched laterals develop. The cord-like lateral roots radiate from the tree at irregular intervals but generally in a spoke-like fashion, remaining close to the surface (usually within 10 to 45 centimetres). They may attain a length in excess of tree height in young stands, reaching up to 12 metres. Fine roots, usually concentrated near the surface, develop along the main lateral roots. Vertical "sinkers" descend from the laterals. The considerable length of the lateral roots means that very large areas are shared by the root systems of a number of trees.

Vertical roots may penetrate to a depth of about 4.5 metres. When taproots and sinkers meet an obstacle, they tend to follow its surface and turn downward at the first opportunity.

The nature of the material in which roots grow distinctly influences their extent and character. Loose, well-drained soils permit deep penetration of vertical roots. Underlying fractured sandstone and siltstone may be penetrated by red pine roots where there is good soil drainage. Fine roots may proliferate just above and below thin layers of finer textured material in otherwise coarse soils. Impeded drainage restricts the downwards growth of red pine roots, and root dieback is common in soils saturated for more than three months of the year. Hardpan gley near the surface and coarse compacted soils also stunt root systems (Fig. 2).

Figure 2. *A plantation root system: The intermeshing and grafted root system of plantation pine is illustrated in this 17-year-old plantation, planted at 1.5 m x 1.5 m spacing. The average tree has lateral roots some 9.7 m long and a total of 67.6 m of laterals. (Photo courtesy of the Canadian Forestry Service.)*

Natural grafting between root systems of individual trees is common. Above-ground evidence of this, is the continuing survival of stumps and stem-girdled trees in thinned stands. These are sustained by manufactured food (no longer available from their own crowns) passed to their roots via grafts with living trees. The dominant member of a grafted pair does not benefit from the connection: if the two trees are equally dominant, a balanced exchange of food occurs; if crown classes are unequal, food moves to the lesser tree; if one member of a grafted pair is cut, the stump may be kept alive, passing water to the living tree, and receiving food in exchange.

In summary, red pine root development and requirements have the following management implications. Root systems may be modified by soil conditions and poor drainage is inimical to red pine roots. The wide and irregular dispersal of roots makes it impossible to judge the origin of root competition with respect to a given tree, or to give that tree full underground release simply by removing its immediate neighbours. Local application of fertilizer or herbicide to the soil may find multiple targets reducing the effectiveness to the targeted tree. Root grafting may further confound results of these operations. Stem-applied herbicides can kill other trees, via root grafts. Disease can be spread by grafts, and infection rate may accelerate after a thinning which itself leads to increased grafting.

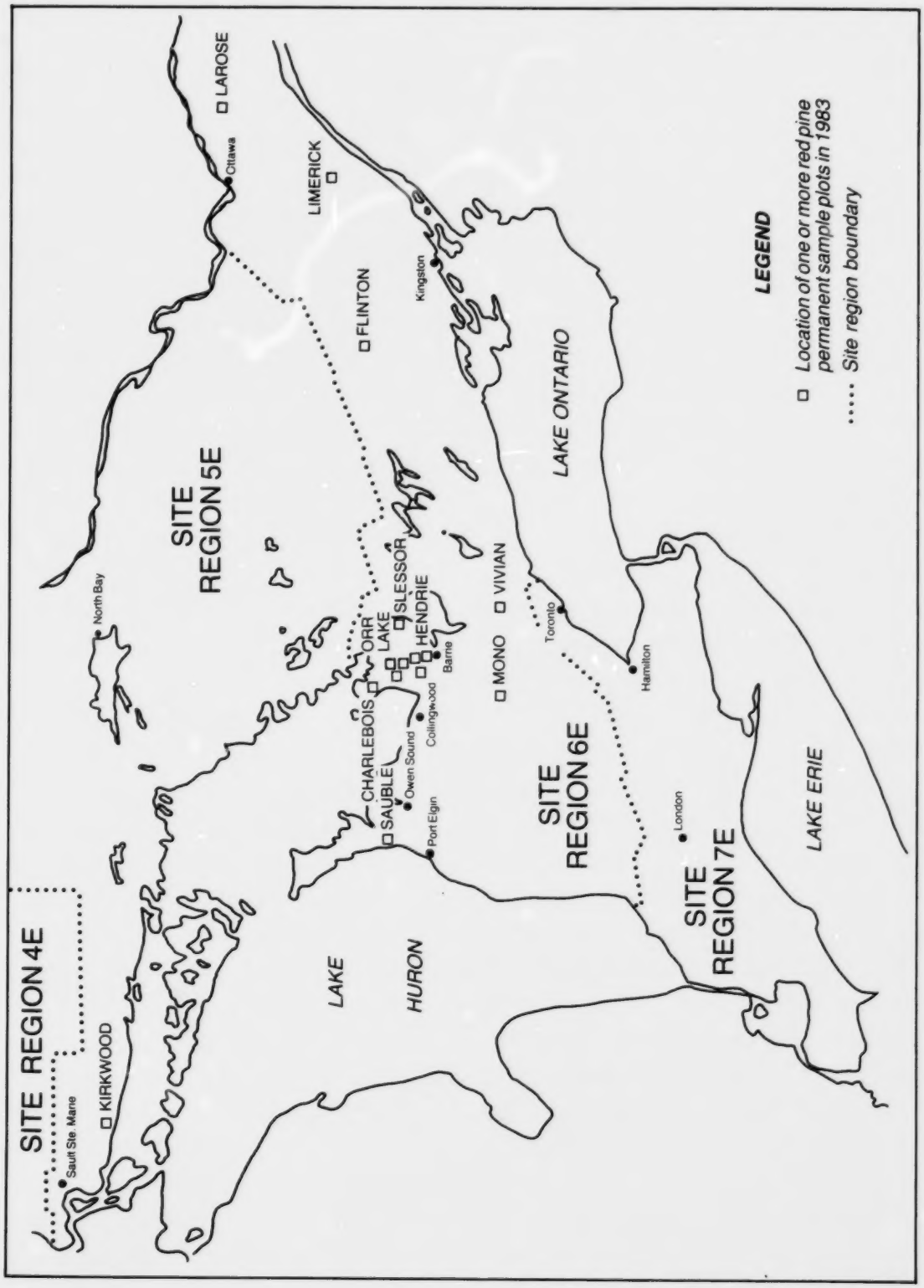


Figure 3. *Forest site regions: Site regions in southern Ontario and MNR permanent sample plots.*

II. SOIL AND SITE REQUIREMENTS

Red pine is a species which will tolerate droughts associated with dry sites on rapidly drained, coarse textured soils, but will not tolerate lack of aeration associated with moist or wet sites on poorly drained, finer textured soils. In natural forest stands, red pine occurs predominantly on soils that are sandy or coarse loamy, stony or stonefree, deep or shallow over bedrock, and rapidly to well-drained with dry to moderately fresh moisture regimes. Within the natural climatic range of red pine in Ontario, these coarse soils are largely acidic, being derived mainly from Precambrian crystalline rocks. Brunisol and podzol soil profiles are typical. The best growth of natural red pine is found on well-to moderately well-drained, fresh to very fresh, coarse loamy and (sometimes) fine loamy soils. However, competition is very high on these sites and red pine becomes established only when severe disturbance and good seed supply coincide. On sites more moist than these, red pine is not normally a component of natural stands.

The widespread planting of red pine in southern Ontario has extended this species into areas and site conditions where otherwise it would not have grown. Most of the plantations in site regions 6E and 7E (Fig. 3) are growing on sandy or loamy soils, although there are a significant number of plantations on silty and clayey soils. Virtually all sites were cleared and cultivated prior to plantation establishment. This history of land use resulted, to various degrees, in the reduction of organic matter, loss of available nutrients, degradation of soil structure and even loss of soil material through erosion. The underlying soil parent materials frequently are not acidic and contain Paleozoic limestone and dolostone particles in varying amounts. Soil deposits containing high percentages of these particles may have pH values higher than 8.0 in the unweathered layer.

Opinions regarding the influence of lime content on successful long-term growth of red pine differ perhaps as much as, and related to, the differing lime content of the soils (Fig. 4). Root development of red pines in the field is predominantly in the weathered soil horizons, which are normally leached free of lime. However, a lack of rooting in the unweathered parent material is observed in both non-calcareous and calcareous soils. Soils with high lime content usually have only a shallow weathered profile which likely inhibits full expansion of the root system. Red pine can be grown quite satisfactorily on sandy and coarse loamy soils with not more than a weak lime reaction below one metre as evidenced by only modest fizzing with hydrochloric acid. However, if the reaction gets stronger and higher up in the soil mantle or the soil texture becomes finer, the choice of red pine for planting should be questioned. In a number of plantations, red pine trees have become chlorotic and have died after 25 to 40 years of reasonable growth. The soils associated with this phenomenon usually have stony, calcareous sandy loam to loam parent materials in glacial till or ice-contact fluvial deposits. Although not all plantations on such sites exhibit these symptoms, forestry staff should be aware that decline and death might occur here before normal rotation age is attained.

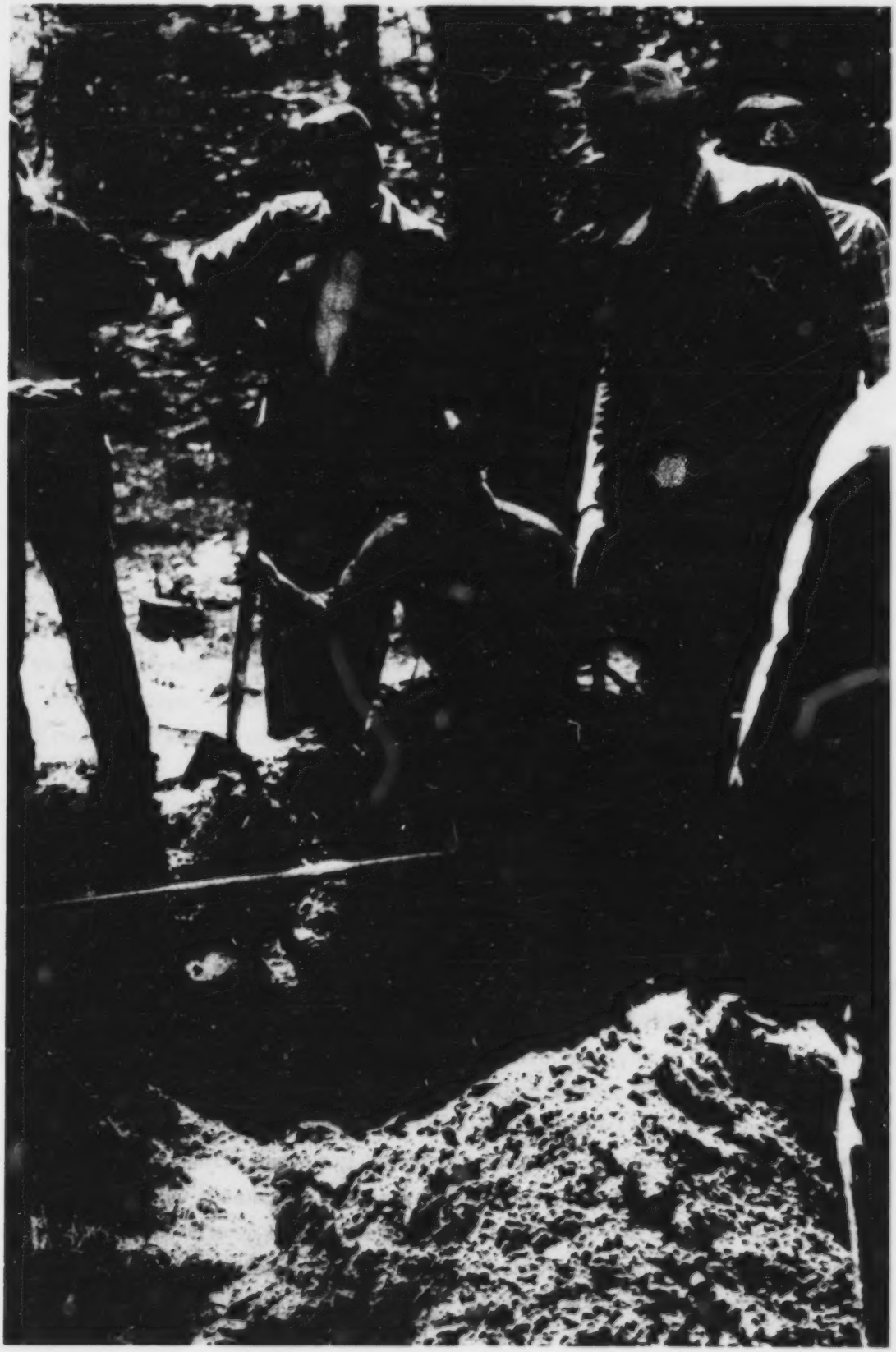


Figure 4. *Soil and site requirements: Forest managers discuss the influence of soil and site conditions on the performance of red pine plantations.*

High bulk density soil has been observed to restrict the growth of red pine roots in both calcareous and non-calcareous soils. This has been noted both in the greenhouse and the field. Such restriction applies to many species, of course, but it may be less significant for species with rooting habits characteristically less shallow than those of red pine. The shallowness of soil over bedrock can restrict root development and tree growth, particularly if soil depth is less than 60 centimetres. However, growth will also depend on slope position as it influences moisture supply. For red pine, the chemical nature of the bedrock is also important. Calcareous bedrock generally denotes lime soil material, which is more restricting to root growth in these shallow conditions than is non-calcareous material.

Layers of fine textured material in sandy soils at depths as great as two metres can influence the growth of red pine. Even a thin layer can delay water drainage enough to improve the water and nutrient availability in otherwise drought-prone soils and hence contribute to better root development and growth. If drainage is severly impeded, resulting in a perched water table and poor aeration for a significant period of the year, growth may suffer. A soil auger should be used in the field to check for these fine soil layers.

Appendix A, "Soil and Site Requirements", presents productivity data for red pine growing on specific soil/site conditions in site regions 6E and 7E. These data consider earlier work in the evaluation of red pine production in relation to soil/site conditions, but are based mainly on the most recent (1980 – 85) evaluation program conducted by the Ontario Institute of Pedology, Guelph, for the Ministry of Natural Resources, Central and Southwestern Regions. These data permit the ranking of different soil/site conditions with respect to their potential for producing red pine.

There are two types of tables involved. Both types give predicted site index values. These are estimates of the height of dominant trees at age 50, which are determined from actual measurements of height and age of trees sampled as well as from site index tables in the new red pine yield tables (Appendix D). The predicted volume production can be determined from the yield tables by using the appropriate stand density value. Tables 6 to 9 (Appendix A) use a framework of soil texture plus drainage/moisture regime as indicated by depth to mottling, the identification of which would normally be made "on-site". Tables 10 and 11 use the soil taxonomic units (soil series) by which the Ontario Soil Survey map units are described. Forestry staff may use the soil survey maps and Tables 10 and 11 to forecast plantation performance during pre-planning in the office and before the actual soil conditions within a specific site are determined in the field. It is recommended, however, that the actual soil conditions be checked as early as possible.

Generally, tree growth increases from the rapidly drained, dry sites to moderately well-drained, very fresh sites, and then begins to decrease on imperfectly drained, moist sites (Tables 6, 7, 8, 9). A good rule is to plant red pine on sites no wetter than very fresh, unless there are other reasons for choosing red pine instead of an alternative species that is highly productive on moist sites.

In summary, planting of red pine is not recommended if any of the following conditions exist:

(a) lime reaction with hydrochloric acid within 50 centimetres of the mineral soil surface;

(b) distinct mottles within 50 centimetres of the mineral soil surface;

(c) material of high bulk density within 60 centimetres of the mineral soil surface.

It should be remembered also, that well-drained to moderately well-drained, fine textured soils usually provide strong competition from unwanted vegetation.

III. STAND ESTABLISHMENT

Provenance

Although genetic variation in red pine is not great, there is significant geographic variation, which makes it important that the planting stock be compatible with the origin of the seed (i.e. seed zone). Seedling stock should be developed and planted within its own seed zone to ensure maximum field performance.

Site Preparation

The amount of site preparation required depends on the severity of the competition present. The following types of site preparation are commonly used:

(a) machine planting with simultaneous furrowing using machine-mounted scalpers;
(b) shallow furrowing by plow, followed by hand planting in the furrows;
(c) hand scalping to remove the sod, followed by hand planting;
(d) machine planting (without scalpers) and simultaneous application of herbicides from the rear of the planting machine;
(e) hand planting without scalping, followed by an immediate herbicide application.

Growth and survival in the outplantings should be assessed during the first few years to determine whether a second or third herbicide application is required (see Plantation Evaluation).

Nursery Stock

The red pine stock presently being produced for reforestation is 2 + 0, 3 + 0, and 1 + 2. The stock type selected for a planting project will depend to a large extent on the degree of site preparation used and on the amount of subsequent tending planned.

The 2 + 0 stock will do well only on sites that have little to no competition or where the competition will be controlled for at least two years after planting. It is not advisable to use 2 + 0 stock on most planting chances in southern Ontario.

The 3 + 0 stock type has given variable results and its success depends greatly on stock qualities such as sturdiness and root-shoot ratio balance. In general, transplant stock is sturdier than the currently produced seedling stock and has proven superior in survival and growth, thus resulting in rapid plantation establishment. The 1 + 2 stock type is the recommended transplant stock. The two most important and useful morphological parameters in assessing planting stock quality are root volume or root area index and stem diameter.

Stock Handling

Red Pine stock should be planted in the spring before any sign of growth activity, such as bud elongation and white root tips, becomes apparent. Fall plantings are not recommended. Spring-lifted stock can be cold stored (1°C) for as long as four to six weeks, without loss in vigour, provided the stock is lifted prior to any growth activity.

Stock that shows signs of growth activity, such as white root tips and initial signs of bud elongation should be planted as soon as possible. Stock with advanced bud elongation should be discarded. The planting stock should be kept cold (1°C) during transportation from nursery to the planting site and kept shaded and cool until planting time. It is better to leave the trees in the shipping container under cold conditions than to heel them in. Heeling-in and prolonged root soaking (longer than four hours) is not recommended. However, dipping roots in water just prior to planting and adding water to the planting pails or bags are recommended. The planting stock, particularly the roots, should not be exposed to the sun or wind. Root pruning at time of lifting should be kept to a minimum. If more root pruning is necessary it should be done just before the trees are placed in the planting pails or bags. Quality control is more difficult in hand planting operations than in machine planting operations and hence the former requires extra planter training with frequent checking by planting crew supervisors.

Spacing

The spacing between rows and trees in rows will affect the thinning options available in the future. Based on current problems related to access at first thinnings, the rows should be at least 2.1 metres apart while spacing within a row should average 1.8 metres. The direction of the rows should be determined after considering access, topography, safe machine operation and prevailing wind direction.

Species Mixture

Red pine is a shade intolerant species and is often planted in pure stands. However, there are some options that can be considered. Alternate rows of red and white pine are suitable for small plantings of four hectares or less or where markets for small wood produced from early thinnings are scarce. On sands and loamy sands, the red pine often suppresses the white pine particularly where white pine weevil is active. This eliminates the necessity of carrying out early thinnings for stand release. Many excellent pole quality stands have been produced from plantings of alternate rows of red and white pine.

While a system of alternate rows of the two species has definite benefits, the planting of alternate individuals of the two species in the same row is of no commercial benefit. In this case, the red pine normally suppress the white pine on all sides, resulting in large branch diameters, which makes the red pine unsuitable for future poles. Thus, a high value intermediate product is forgone while an exceptionally high planting cost is incurred.

The planting of alternate rows of red pine and Scots pine (*P. sylvestris* L.) has been tried but is not recommended because of high protection and tending costs.

The establishment of white pine (*P. strobus* L.) or red oak (*Q. rubra* L.) for a future seed source is often an important consideration when red pine plantings are being planned. Regeneration of these species occur under red pine about 40 to 45 years after planting, when the stand has been thinned three or more times. Seed dispersal is aided by the activities of red squirrels at that time.

Red oak should be set out in a solid block 17 to 20 metres wide and not less than 20 metres in length in order to minimize rodent damage. While pine plantings from age five to twenty provide useful cover for grouse feeding. They also provide habitat for hares which damage or destroy hardwoods which may be located in close proximity to the plantings.

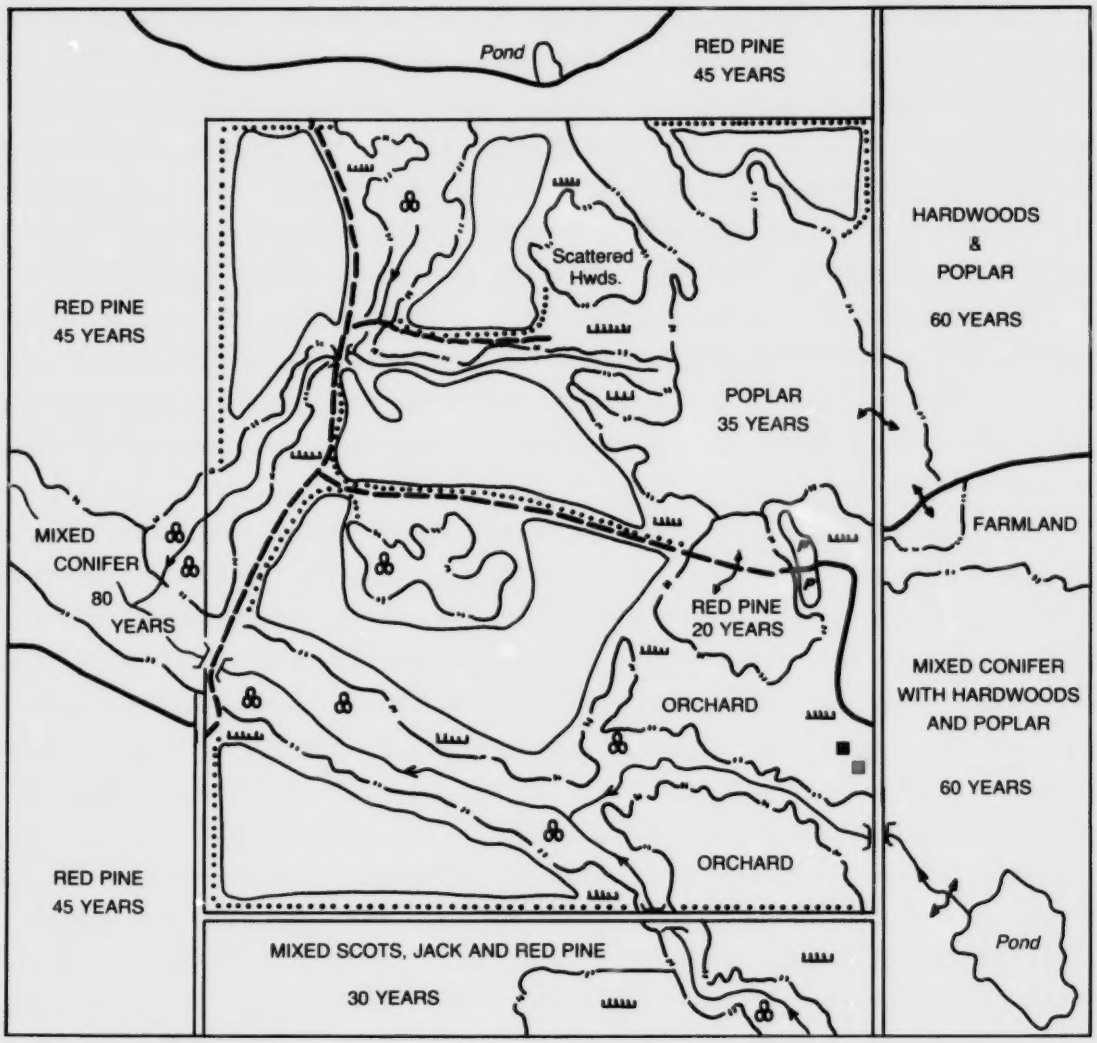
On sites well-suited to red pine, a sequence of nine rows of red pine with three rows of white pine can be set out. Where the site is more favourable to white pine, five rows of red pine with three of white pine is recommended. In each case, the red pine rows adjacent to the white pine would be removed in the first thinning operation. On marginal red pine sites, one row of red pine with three rows of white pine provides for the removal of all red pine rows in the first thinning. In this case, the thinning will release the stand and at the same time produce a marketable product of red pine thinnings.

Wildlife Considerations

Figure 5 shows a typical 113 hectare block of land in south-central Ontario. The topography is gently rolling, fractured by gulleys and ravines with seepage areas. The soils are mainly deep, medium to fine sands, non-calcareous within one metre of the surface. The land has been abandoned for farming for more than 30 years, and the owner's objectives are timber production and outdoor recreation in its broadest sense, including hunting, skiing, snowmobiling and horseback riding.

The ravines at present are used—spring to fall—by woodcock and song birds and to some extent by ruffed grouse, white-tailed deer, and varying hare.

The proposed road system is set out in wide corridors of up to 20 metres. Open areas are set out to be retained between the proposed plantation and other cover types. These open



Legend:

- Township Road (Public)
- Internal Road (Private)
- Proposed Internal Road
- Open Grassland
- Stream with direction of flow
- Proposed Planting by Machine (with row direction), rows 2.1m apart, trees 1.8 m apart.
- Alders, Dogwood (Damp)
- Fuelbreak 5m width (ploughed/disced)
- Pond or Water Hole
- Building

Scale
0 500
meters

Figure 5. *Typical planting project: Red pine seedlings will be machine planted on this property in Simcoe County. The planting plan design provides for optimum wildlife habitat and protection against ground fires entering the plantation.*

areas will eventually be used for piling and peeling the pulpwood extracted in future thinnings. Furthermore, they are useful for maintaining ploughed fuel breaks and may be planted later with apple, rose, cherry and hawthorn by the owner. Seeding-in with aspen (*P. tremuloides* Michx.) will also take place. Periodic mowing by the owner to prevent dense brush from becoming established in these openings is usually recommended in the management plan.

Carrying out the planting program over a number of years, would further improve wildlife habitat conditions. Similarly, scheduling future thinnings and harvest cuts so that all areas are not treated at the same time will yield greater diversification of cover conditions.

A plantation of red pine contributes little in the way of habitat to harvestable wildlife. However, it does provide cover for deer movements, some opportunity for grouse to roost, and for a few years after planting a habitat for varying hare. It also provides habitat for red squirrels and some songbirds. The red oak and white pine species recommended for planting with red pine, should provide added benefits, especially if planted along the edges of the plantation as well as the interior. White cedar (*T. occidentalis* L.) planted near winter deer cover (southwestern part of the property) will eventually be utilized by deer.

In the project area large unbroken tracts of pine plantations are minimized, while commercial timber production is part of the management considerations. The old orchard in the southeastern part will get more fall use by deer. The poplar area in the northeastern part of the property will be productive for wildlife if the owner carries out periodic patch clear-cuts to promote the maintenance of aspen.

Planting

Ideally, planting should only begin when the soil temperature reaches 5°C and above, because cold soils (<5°C) inhibit root growth and water uptake. Owing to the extent of the planting and a restricted planting season, however, this can not always be done. The stock should be planted at the same depth as it grew in the nursery. Red pine is very sensitive to deep or shallow planting (i.e. two centimetres or more either way) so both extremes should be avoided. The wedge method is the most common and preferred method used when hand planting. The trees must be planted erect with the roots untangled and spread out (Fig. 6). The soil must be carefully but firmly tramped around the roots to eliminate air pockets.

Machine planted trees must be set in an upright position with the roots placed well down in the slit and sufficient pressure must be applied by the packing wheels to secure the roots in the soil and so eliminate air pockets (Fig. 7).

Figure 6. *Hand planting of 3-0 red pine at 2.1 m x 1.8 m spacing on a 1983-84 cutover, scarified with Young's teeth. (Simcoe County Forest, Sunnidale Township.)*

Plantation Evaluation

When planting has been conducted in accordance with the guidelines outlined above and high quality planting stock has been used, the survival and subsequent growth will be high and there should be no need for infilling. Nevertheless, plantation survival and growth should be evaluated annually the first three years. In the initial years, survival will be an important parameter. But the degree of establishment is also important, the latter being determined by examining the needle length of new growth.

Survival only, indicates the number of trees that have overcome the initial planting shock. If the trees are not well-established during the first two years, further losses will occur in years three to five. By evaluating the degree of establishment, the future success of the plantation can be predicted. This early evaluation should be accompanied by recommendations for refill and/or seedling release where required.

The needle length and growth characteristics of the terminal shoot should be examined the first two years after outplanting. Long needles indicate good establishment has been achieved whereas short needles indicates poor establishment. A substantial increase in needle length from the first to second year after outplanting indicates good root growth whereas a slight increase or reduction in needle length indicates poor root growth and hence poor establishment.

A technique for predicting plantation performance in the first two years after outplanting is discussed by J.M. Paterson and D.C.F. Fayle.[1] The technique provides a sound basis for outlining tending recommendations by the end of the second year after planting.

1. Early prediction of plantation performance for red pine, 1984, For. Chron. 60: 340-4.

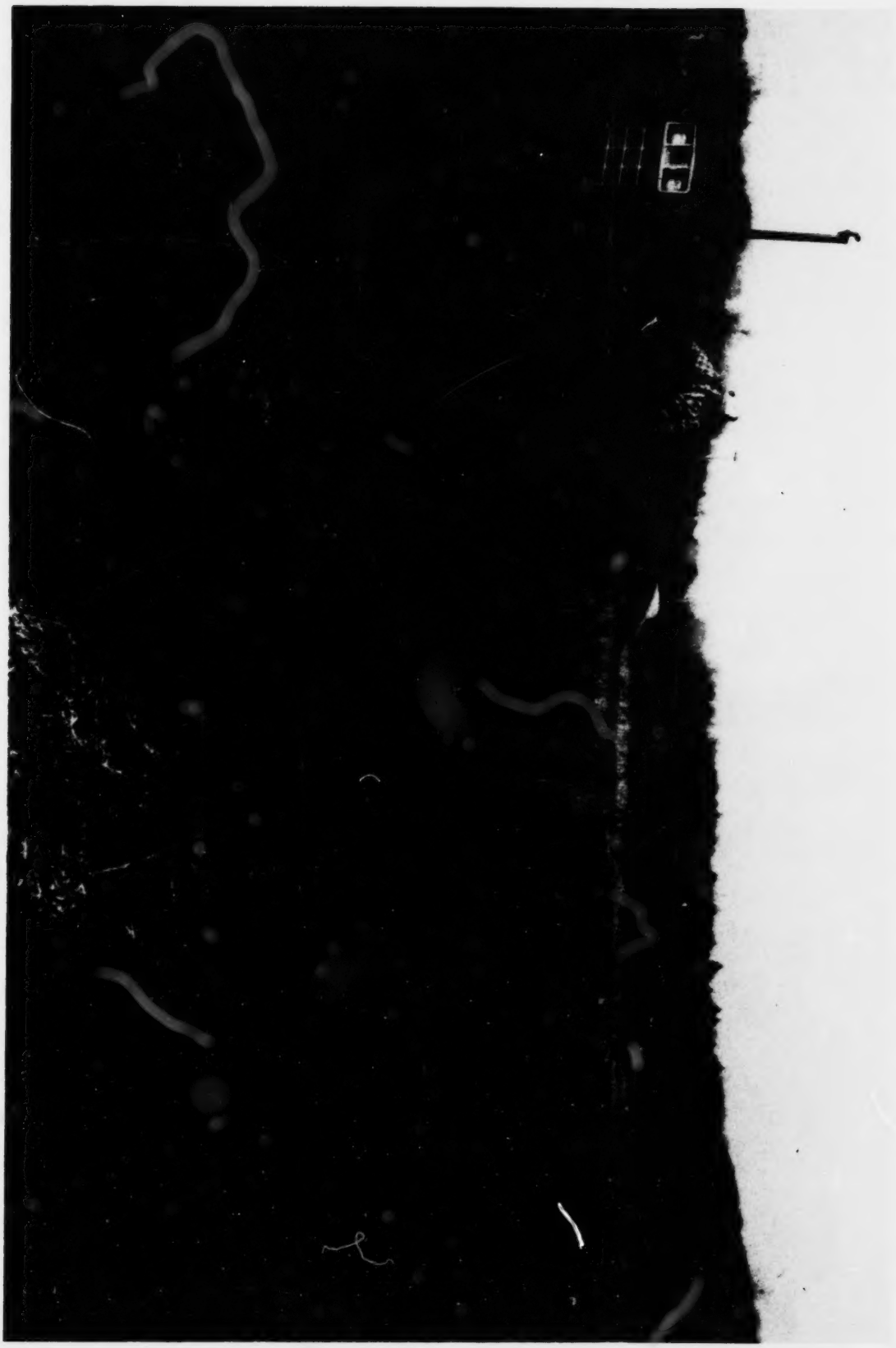


Figure 7. *Machine planting at 2.1 m x 1.8 m spacing using a Michigan tree planter.*

IV. FIRE

Fire Behavior

Red pine plantations are highly flammable forests. The fuel complex, composed of clean, loosely-packed litter, dry flaky bark, and a continuous layer of crown foliage, is made to order for intense fires.

In the following material, familiarity with the Canadian Forest Fire Danger Rating System (CFFDRS) is understood. The system has two parts: the Fire Weather Index System (FWIS) and the Fire Behavior Prediction System (FBPS).

FIRE DANGER

In the FWIS, the codes and indexes indicating the main aspects of fire danger in red pine plantations are:

- Fine Fuel Moisture Code (FFMC)—the moisture state of red pine surface litter
- Duff Moisture Code (DMC)—the moisture state of the underlying forest floor (the duff)
- Initial Spread Index (ISI)—the rate of spread of fire, including the whole range from surface to crown fire
- Fire Weather Index (FWI)—the intensity of fire in terms of energy output rate per unit length fire front

FIRE SPREAD RATE AND INTENSITY

The FWIS provides information in the form of relative codes and indices. The FBPS is based on the FWI, and provides quantitative estimates of rate-of-fire spread and fire intensity. For this purpose, red pine plantations are classified in three height classes, namely less than 10 metres, 10 to 20 metres, or greater than 20 metres. Figures 8 and 9 chart spread rate and intensity for a normally expected rate of fuel consumption, as related to ISI and FWI, respectively.

CROWNING TENDENCY

Red pine plantations are progressively less prone to crowning as they age and grow. At heights well over 20 metres the fire will stay on the ground for the normal range of fire danger. Fire in younger and shorter plantations, however, especially after crown closure, crowns readily as the ISI reaches moderate to high values. In any event, a requisite for crown fire is a strong wind, without which the fire may burn all day on the ground, no matter how dry the surface fuel.

PHYSICAL UNITS

Commonly used physical units for pertinent quantities in the forest fire business are:

- Rate of spread (linear)—metres per minutes (m/min)
- Fuel weight (present or consumed)—kilograms per square metre (kg/m^2)
- Fire intensity—kilowatts per metre of front (kw/m)

Fire Damage and Mortality

Crowning fire will, of course, kill pines of any size outright. Surface fire may or may not kill the trees, depending on both tree size and fire intensity. There are two mechanisms of fire damage: stem damage and crown scorch. Too much of either will kill a red pine tree.

STEM DAMAGE

Stem damage to only part of the circumference will cause a fire scar, but will not kill the tree. Pole-size red pines may live for decades with more than three-quarters of the circumference scarred. Even a completely girdled pine may take several years to die.

CROWN DAMAGE

Crown damage (or crown scorch), if complete, kills the tree quickly. Even so, if the fire occurs in the spring before the new growth flushes the tree may survive; because the buds, being thicker, may live even though the heat may be enough to kill all the over-wintering foliage. If a tree in summer sustains a 75 percent crown scorch, it has about a 50 percent chance of surviving.

TREE SIZE

Small trees are easily killed by either stem or crown damage. As the diameter and bark thickness increase, the cambium is increasingly well-protected, and crown scorch becomes the more likely means of damage or mortality by fire.

The amount of crown scorch caused by a surface fire depends on how high the lethal heat is carried by the heat convection rising above the flames. This height depends mainly on the fire intensity.

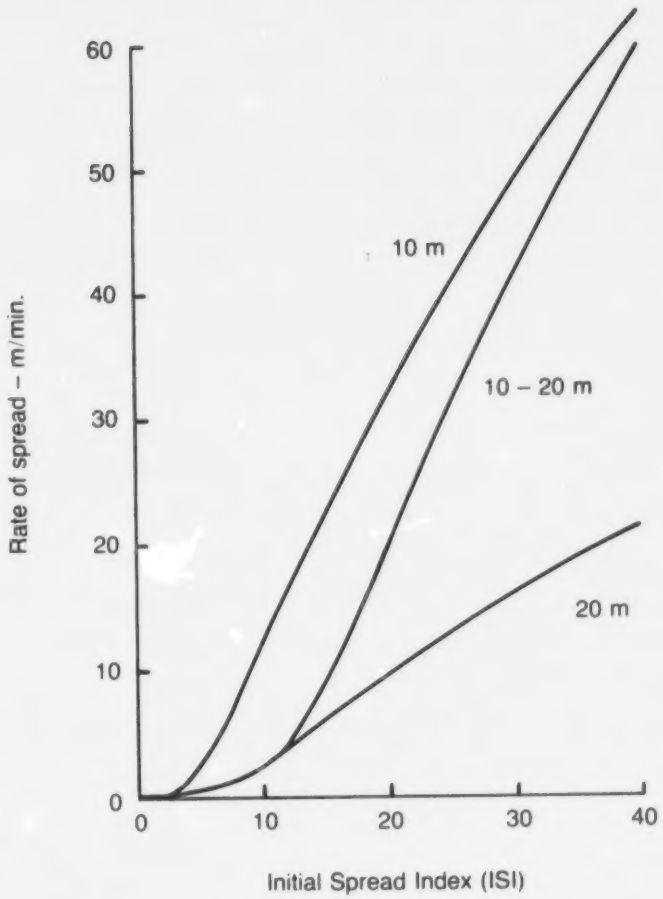


Figure 8. *Fire spread in plantations: Relationship between the rate of fire spread and the ISI for three height classes of red pine plantation.*

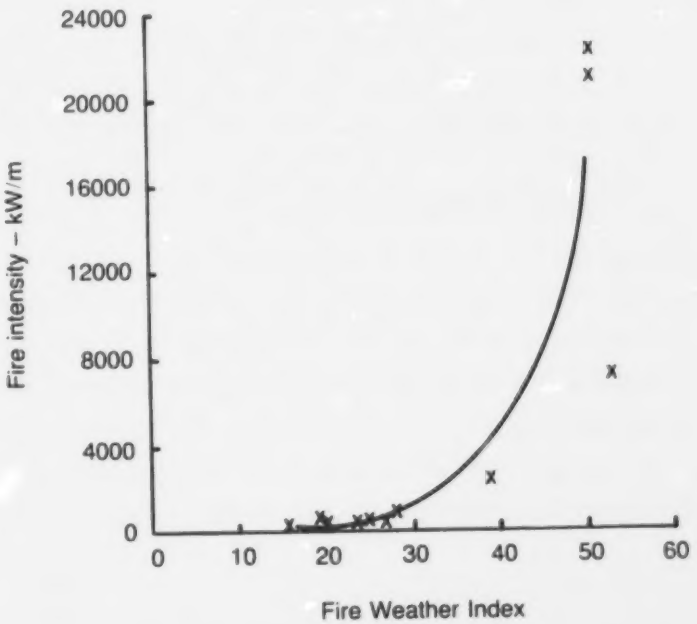


Figure 9. *Fire intensity and Fire Weather Index (FWI): Relationship between fire intensity and FWI for red pine plantations of medium height (about 15 m); based on 11 experimental fires at Petawawa, Ontario.*

Fuel In Red Pine Plantations

There are four important kinds of fuel in red pine plantations:

- surface litter—mainly the last fall of needles plus dead twigs and shed bark;
- duff—defined as the forest floor underlying the litter;
- crown foliage;
- thinning slash.

Dead lower branches and flaky bark constitute minor fuel in terms of quantity. Such "ladder fuel" may contribute somewhat to the crowning hazard, but the initiation of crowning depends primarily on the development of an intense surface fire.

LITTER AND DUFF

The litter and duff layers are fairly independent. The moisture content of the litter layer follows the day-to-day weather as indicated by the FFMC, whereas the duff layer responds to weather over periods of a week or more as indicated by the DMC. No fire danger exists unless the litter layer is dry enough to allow fire to spread; any fire will then be more intense if the duff as well as the litter is fairly dry. Nevertheless, on a dry windy day soon after rain, the litter can support a fast-spreading fire without much duff involvement. Conversely, on a calm muggy day after considerable drought, a fire may burn deeply without spreading very fast.

CROWN FOLIAGE

A crown fire usually consumes the foliage only, twigs and even newly-flushed buds may remain unconsumed.

Red pine foliage, like other conifers, undergoes a seasonal drop in moisture content that renders it distinctly more flammable during May and June than in the rest of the fire season. For any given daily weather, therefore, the fire's tendency to crown is greater during this period (Fig. 10). This tendency is more dependent on the height to the live crown base than on ladder fuel such as flaky bark and dead branches. As the crown base height increases with total height and age, the plantation becomes less and less susceptible to crowning.

SLASH FROM THINNINGS

The addition of slash to the surface fuel, after thinning, greatly increases its flammability. Slash adds considerably to the total surface fuel weight, and its fuel arrangement is ideal for combustion. In addition, thinning opens the stand to the wind, which will then be stronger on any given day in the thinned than in the unthinned plantation. Because of this combination of added fuel and stronger wind, the effect of thinning is to increase flammability particularly at moderate and low fire danger. The ease of crowning may indeed be somewhat reduced owing to the resultant discontinuity in the crown layer. But the surface intensity at high or extreme fire danger would scorch the crowns

whether the fire crowned or not. In any case, complete mortality would occur.

FLAMMABILITY AND AGE

The flammability of a red pine plantation varies in a complex manner with age:

(a) During the first few years, flammability depends on the kind of minor vegetation between the trees. Grass, for instance, is flammable in spring and fall, but seldom in summer.

(b) Once the crowns close and a continuous needle litter forms, flammability becomes high, and continues until the tree height reaches about 15 metres.

(c) The increasing vertical gap between surface fuel and crown base causes the crowning tendency to decrease as the tree exceeds 20 metres.

(d) Development of minor broadleaved vegetation under the canopy will generally decrease flammability; however, an understorey of balsam fir trees at moderate density will increase it.

(e) Thinning at any time, with the slash left in place, will markedly increase flammability at any age.

Figure 10. *A crown fire in a pine plantation is its death knell. Young plantations are particularly vulnerable and can be wiped out in minutes. (Photo courtesy of the Canadian Forestry Service.)*

Design and Management For Fire Safety

Red pine plantations should be established and managed with fire safety in mind. The aim should be to provide easy access and to minimize the area burned if intense fires occur.

ROADS AND FIREGUARDS

The first requisite is a network of roads, or at least ploughed fireguards of good enough quality to support tank trucks and four-wheel-drive vehicles. The density of the road network will be ascertained from a predetermined judgment of the maximum single burn area that can be tolerated for practical purposes.

Ploughed fireguards will stop gentle fires, but not intense surface or crown fires. Their main purpose is to provide access and to be used as lines for fire-fighting.

CONTINUITY

Fire safety suggests that the continuity of a red pine plantation be broken up by more than a network of fireguards; in other words, by strips or blocks of less flammable vegetation such as hardwood forest. Even if these hardwood areas are not completely fireproof, they offer a greater chance of stopping fire than does a red pine plantation. The arrangement and size of such strips or blocks depend to some extent on the single maximum loss that can be tolerated when a fire cannot be fought within the plantation. To be useful, these intervening strips should be at least 50 metres wide so that they will provide a half an hour or more of low intensity fire and thus allow for easy control.

PRUNING PLANTATION EDGES

The question sometimes arises whether pruning the lower branches along the edges of a plantation will reduce the chance of a fire crowning. It is true that wherever a plantation is well exposed to the wind, surface fire running up to the unpruned edge will climb readily into the tree crowns. However, there are two arguments against such pruning. One is that by opening up the edge, the litter inside is more exposed to sun and wind, and therefore more flammable. The other is that the main requirement for a continuous crown fire in a red pine plantation is a surface fire of sufficient intensity to support crown combustion. This means that once the fire has penetrated the plantation a short distance, its behaviour will be more or less independent of fuel arrangement at the edge. An edge open to the wind could, in fact, enhance the probability of crown fire penetrating a considerable distance into the stand.

Instead of pruning the branches from the edges of the plantation, a better practice would be to carefully control the grass or minor vegetation along the edges, and hence reduce the intensity and continuity of any fire-front that does reach the plantation.

PRESCRIBED FIRE FOR HAZARD REDUCTION

The question periodically arises as to whether surface litter or thinning slash can be burned safely at a time of low fire danger in order to render the plantation less flammable when high danger occurs. The evidence gathered from experimental fires at Petawawa leads to the conclusion that this is not generally feasible. The flammability of a red pine plantation, either thinned or unthinned, is at its height during the first half of the rotation, and coincides with the period that its susceptibility to fire damage is also at its peak. Later on, when the trees are larger and taller, surface fires could be run through a plantation with reasonable safety, but by then the danger of damage is also less. A fair conclusion is that the organization and layout of a red pine plantation should be such as to minimize both the chance of a fire starting and the area likely to be burned if one does start. Then, the manager should be prepared to accept whatever loss his fire control organization is unable to prevent.

Fire Control

Because of the high value and flammability of red pine plantations, quick detection and a fast attack should be the keystone of fire control strategy. The most effective fire-fighting tactics are the plentiful use of water and burning out or backfiring. These operations are dependent on a network of roads. Hand tools should be considered for backup and are useful when a fire can be fought within a plantation block. Aircraft equipped for water or retardant dropping would be useful, but only if based within the region and on immediate call.

DETECTION

Under conditions of high or extreme fire danger, fast detection is of utmost importance. Fire reporting by an occasional air patrol or by the public may suffice under low or moderate danger but cannot provide adequate insurance against serious loss on special days when a few minutes could make the difference between success and failure. On these extreme-hazard days fire detection can be enhanced by frequent air patrols, ground patrols, and day-long surveillance from towers if the latter are present in the district.

ATTACK METHODS:

The best attack system is undoubtedly a combination of tank trucks and an adequate network of access roads. Pumps and hose-lays would match the efficiency of tankers only if there are enough strategically located water sources. In other words, a plentiful application of water is the first key to quick suppression.

The second key, especially for high-intensity surface fires and crown fires, is burning out against the wind ahead of the main fire front, namely backfiring. This operation requires skill

and adequate time. It calls for the deliberate write-off of a block of plantation, but the area sacrificed would presumbly have burned anyway. Minimum lead time required for this operation is in the order of 20 minutes. A backfire can be assumed to spread at about one metre per minute in very dry litter, and a burned out strip of about 20 metres stands a good chance of stopping a crown fire.

The required safe lead distance would be determined from an estimate of the head fire's of advance, either by direct observation or from Figure 8. At ISI 20, for example, a fire could spread at 25 metres per minute. The lead distance for a 20-minute burning out operation would then be 500 metres. The operation would, of course, be carried out from a road or fireguard roughly at right angles to the wind direction.

If the plantation is well-interspersed with areas of less flammable forest, backfiring is not necessary, because direct water application plus, perhaps, hand tools will stop any fire in hardwoods.

While head-on attack is being contemplated or is underway, equal consideration should be given to flank control. This is the conventional technique of pinching a fire as it advances, eventually catching up with the head. This method will only minimize the burned area effectively if the rate of line-building along the flanks exceeds the rate of headfire advance.

V. PEST CONTROL

Insect Pests

Insects are among the most abundant forms of life in any plantation and exert a continual influence upon the trees as they develop. The degree of injury they inflict depends upon the intensity of the insect infestation, their feeding habits, the time of year the injury occurs, the age of the tree, and how vital the part of the tree attacked is to its survival. Growing trees in even-aged monocultures, and to a lesser extent in mixed-species plantations, often provide conditions conducive to outbreaks of insect depredators. Economic and aesthetic losses, however, can be kept to a minimum by practising a five step control program:

- Inspection at frequent intervals to establish "normal" tree condition and insect status
- Detection of abnormalities in tree growth or fluctuations in insect populations in the incipient stage
- Identification of the cause(s) of the aberration
- Evaluation of the potential for injury and the necessity for artificial control measures
- Suppression by the most economically effective and environmentally acceptable means.

Over 500 species of insects have been recorded attacking pines in Ontario. Only a few of these have occurred in numbers sufficient to cause serious economic damage to red pines. Nevertheless, at least one type of injurious insect is of importance in each of the broad stages of the tree's development.

CONE AND SEED PESTS

Almost all insect damage to red pine cones takes place during the second or final year of cone development. Probably the most destructive pest is the red pine cone beetle, *Conophthorus resinosae*. It is present wherever its host occurs in numbers, and in some years is a limiting factor in the production of adequate cone crops of acceptable quality. The adult beetles are black, cylindrical, and only three millimetres long. They attack the second-year cones at the base and bore into the cone's centre to lay their eggs from May to mid-July. The tiny white larvae feed indiscriminately on seeds and scales. When cones are scarce the beetles can complete their life cycle in the red pine shoots. No control is presently available. But investigations into methods and materials for reducing seed losses will have to receive greater attention as more seed production areas and seed orchards are established and intensively managed.

Other insects of lesser importance are the coneworms *Dioryctria disclusa*, *D. abietivorella*, *Eucosma monitorana* and *Laspeyresia toreuta*.

SEEDLING AND TRANSPLANT PESTS

Seedling red pines in nurseries are subject to the ravages of large, fleshy white grubs—the

larvae of the common June beetles, *Phyllophaga* spp. These insects develop in the soil over a two to five year period, and do extensive chewing or girdling of roots during their second season. Larval destruction of the fibrous roots or stripping of the root bark results in the desiccation and death of seedlings and transplants. The concentration of tender roots in nursery beds can result in substantial losses during heavy infestations. Additional losses occur when plantations are established on little-used agricultural lands that were recently in sod. Generally, damage is first noted in late summer when the seedlings turn a brown colour and die, exhibiting typical symptoms of drought damage. Insecticides thoroughly worked into the soil of nurseries will give protection to the seed. The root systems of seedlings may be protected by spraying insecticides at the time of field planting by operating a sprayer attachment on the planting machine, or by dipping the roots of hand-planted stock. Since white grubs are cyclic in abundance, the trees will have three years in which to become sufficiently well-established to withstand attack when the most destructive stage of the grub recurs.

Larvae of the strawberry root weevil, *Otiorhynchus ovatus*, a much smaller insect than the June beetle, inflict a similar type of damage to the roots of young evergreens. The same control measures are effective against this insect species.

SHOOT AND STEM BORERS

Young plantation pines are subject to distortion and stunting by attacks of the European pine shoot moth, *Rhyacionia buoliana* (Fig. 11). During the 1950s this introduced species was such a serious pest that the planting of red pines south and west of a line from Manitoulin Island to Brockville was discouraged. Injury happens when larvae feed within the buds and developing shoots and, to a lesser extent, in the needles and cones. The mined needles turn brown, become loosened, droop, and often fall out of their sheaths. The buds may be destroyed, but elongating shoots injured on one side only continue to grow forming the so-called "bayonet tip". By killing the shoot, the development of latent buds below the injury may be stimulated, thus producing a malformation called "witches'-broom".

The transfer of the shoot moth to new areas via infested nursery stock can be prevented by fumigation with methyl bromide. In plantations, control by chemical insecticides is difficult and on a large scale is not satisfactory for ecological or economic reasons. Silviculturally, it is recommended that where the topography is rolling, red pine should not be planted on dry sites on the tops of hills where they are most vulnerable to attack, but rather they be restricted to moister sites on slopes or in the valleys. If feasible, infested shoots should be pruned in late May and destroyed. Further, the lower branches of smaller trees should be removed to decrease the proportion of the crown that will be under snow. This latter practice reduces the number of overwintering sites that are available to the shoot moth. In addition, during a severe winter, it will help to reduce shoot moth populations as virtually no larvae can survive an air temperature of about –29°C. Young red pines should not be planted in an area where shoot moths are present

Figure 11. *The larvae of the European pine shoot moth feed in the buds and developing shoots of red pine. The injury results in a "bayonet tip" or "witches'-broom". This was a serious plantation pest in the 1950s.*

on older trees, because the moths will move from the older to the younger trees instead of dying out. Biological control of the shoot moth by its several parasites should be promoted by encouraging the growth of certain flowering plants, such as buckwheat, within or around the plantation.

The white pine weevil, *Pissodes strobi*, is another borer whose activities affect stem form, particularly when red pines are planted in mixture with, or adjacent to, white pines or spruces. This small, brownish snout beetle attacks only the vertical terminals, depositing its eggs in pits gnawed in the inner bark just below the buds. The larvae feed in a downward ring formation, destroying at least two years' leader growth. The result is a crooked, forked or multiple-stemmed tree, depending upon the number of branches competing for dominance in the uppermost whorl. Application of methoxychlor or lindane to the leader in early April gives satisfactory protection against infestation. Small trees are best protected by spraying with a backpack or ground sprayers, but trees over four metres tall are more effectively protected by sprays applied aerially. Spraying may need to be undertaken at four to five year intervals until the trees have reached a height of ten metres. Susceptible hosts grown under a canopy of broadleaved trees are relatively free from white pine weevil injury.

The eastern pineshoot borer, *Eucosma gloriola,* feeds on all species of pine, but is of only minor importance in red pine plantations. It affects mainly the current year lateral shoots and seldom interferes with straight stem growth. The larva bores directly into the pith and feeds toward the base of the new shoot, causing it to wilt, turn brown, and break readily at the last point of feeding. Chemical control on a large-scale is costly and relatively ineffective. Where feasible, the infested tips should be pruned and burned before mid-July.

DEFOLIATORS

Several defoliators, mainly sawflies, feed on the foliage of young plantation red pine. Of these, the redheaded pine sawfly, *Neodiprion lecontei*, is the most important (Fig. 12). The larvae are a distinctive yellow colour with a reddish head and six rows of black spots on the body. They may be found during July to early October feeding in colonies. They show preference for the needles of the previous year's growth, but in heavy infestations consume all needles as well as tender bark on young twigs. Defoliation usually progresses from the top of the tree downward. Extensive mortality sometimes occurs in young plantations where the trees are less that five metres tall. Fortunately, this species is quite readily controlled by applications of malathion, methoxychlor, nearly any of the commonly available chemical insecticides, or by sprays containing a nuclear polyhedrosis virus specific to the redheaded pine sawfly. In addition, several parasitic insects, birds and rodent predators are important natural control agents.

Another gregarious defoliator is the European pine sawfly, *Neodiprion sertifer.* The greenish-black larvae are present early in the season and restrict their feeding to the foliage of previous years. Thus the life of the trees is sustained by the current season's needles, but stem diameter may be greatly reduced. Populations of this sawfly can also be readily controlled by most chemical insecticides

Figure 12. *The redheaded pine sawfly can be a serious defoliater pest. Larval feeding strips the previous year's needles. The defoliation extends from tree's top downwards.*

as well as by a specific nuclear polyhedrosis virus, which has the added advantage of transmission to succeeding generations.

The red pine sawfly, *Neodiprion nanulus nanulus*, feeds on most species of pine, but primarily on jack pine. It is widely distributed in Ontario except in the Southwestern Region. Little or no mortality results from a single year's infestation because only the older needles are eaten. But, where defoliation continues for several years, affected trees may be killed.

The pine false webworm, *Acantholyda erythrocephala*, considered a rare and relatively unimportant pest in Ontario prior to 1976, is now found throughout the Central Region. Most species of pine are attacked—particularly Scots pine Christmas trees and plantation red pines. The young larvae spin loose webbing about themselves and feed gregariously on the old needles. Older larvae feed singly from within silken tubes spun along twigs. Heavy infestations sometimes develop locally, causing severe defoliation and detracting greatly from the appearance of the trees. The protective webs make spray penetration difficult, thus insecticides should be applied at the first sign of feeding in June.

SUCKING INSECTS

Nymphs of the pine spittlebug, *Aphrophora parallella*, pierce the bark in the spring to feed on the sap. They soon cover themselves with a frothy mass of spittle composed of tiny air bubbles coated with partially digested sap. When the young change to adults in July the spittle masses desiccate and a black sooty mould often develops at the feeding sites.

Adults of the Saratoga spittlebug, *Aphrophora saratogensis*, also injure red pines, but the nymphs attack only ground cover plants, especially sweetfern. Heavy infestations of either of these species may cause twig, branch or tree mortality the following year. Since the spittle masses give protection to the nymphs, contact insecticides such as malathion should be applied in June as fine forceful sprays.

PESTS OF POLE-SIZE TREES

Pole-size trees are relatively free of injurious insects, although several species of bark beetles may attack trees that have been weakened or placed under stress by other agents. Broods of the pine engraver, *Ips pini,* construct fan-shaped galleries beneath the bark, which in heavy infestations interlace and effectively girdle the stem or larger branches. A generation completes its development in four to five weeks and two generations may be produced in a year. Bark beetles are difficult to eradicate once established. Protection, therefore, centres on removing and destroying weakened and recently dead trees and slash that provide suitable brood-rearing material. Logs should be debarked or utilized as soon as possible after cutting. If necessary, spray susceptible material with lindane.

PESTS OF WEAKENED AND CUT TREES

Further losses in damaged or decadent stands, or in wood that has been cut and not removed from the forest, are caused by the large, white fleshy grubs of beetles commonly referred to as roundheaded borers and flatheaded borers. Common representatives are the northeastern sawyer beetle, *Monochamus notatus*, and the buprestid, *Chrysobothris dentipes*, which is frequently found around sawmills.

Attempts to salvage fire-killed trees, or trees killed by other catastrophies are often rendered uneconomical by these borers, which have riddled the wood with their tunnels. Prompt utilization of dead or dying trees, or peeling of logs is necessary to minimize damage and prevent the buildup of adult populations, which sometimes cause conspicuous feeding damage to the foliage or bark of the remaining trees in the stand. Logs or pulpwood, which must remain untreated in the forest during the period of adult beetle flight in early and mid-summer, should be piled in the shade under a cover of brush or thoroughly sprayed on the exposed surface with lindane.

Diseases

Red pine is morphologically very uniform. Although it has fewer serious enemies than most species within its range, several fungal diseases are important. The impact of disease is intensified when red pine is grown in monoculture since this permits rapid disease spread both above and below ground. Some of the fungal diseases that can be extremely damaging to red pine in nurseries and/or plantations and their control, follow.

FOMES ROOT ROT

Heterobasidion annosum (Fr.) Bref. [= *Fomes annosus* (Fr.) Cke.]

HOSTS AND DISTRIBUTION:

Heterbasidion annosum commonly known as Fomes root rot is distributed throughout the north temperate zone of the world. There are over 150 known hosts for this disease including fir (*Abies sp.*), maple (*Acer sp.*), birch (*Betula sp.*) beech (*Fagus sp.*), larch (*Larix sp.*), spruce (*Picea sp.*), pine (*Pinus sp.*) and oak (*Quercus sp.*). The most important host in Ontario is red pine.

SPREAD:

Red pine, which is grown extensively in pure plantations, requires thinning a few years after establishment. This thinning creates many fresh stump tops that provide an entrance for *H. annosum*. Infection that enters through the stump top is known as "primary infection". Spores that land on the fresh stump germinate if conditions are favourable; the fungus then colonizes the stump and root tissues. Fresh stump surfaces are susceptible to fungal invasion for 10 to

14 days only. After this time, the tissues are altered and will not support *H. annosum* growth. Grafted pine roots provide a pathway for the fungus to spread from infected to healthy trees. This underground spread is known as "secondary infection".

SYMPTOMS:

Fomes root rot causes the decline of an individual or small group of trees. Stunted growth and the yellowing of foliage are typical symptoms. Although dead trees may remain standing for some time, they are eventually windthrown. Dense undergrowth often develops in the circular openings that develop in the stand.

When the roots are considerably rotted, a fungal fruit body (or conk) is produced at or slightly below the ground line at the base of the tree (Fig. 13). The perennial fruit bodies have a grayish-brown to dark brown zoned upper surface and a lighter coloured sterile margin. The lower surface is white-to-biscuit coloured with numerous small pores. The spores are produced on structures that line the inner surface of the pores. When mature, the spores fall out of the tubes and are carried by the wind to infect other hosts.

CONTROL:

The primary infections of *H. annosum* can be controlled by chemically treating the freshly cut stump. Dry granular borax is the best material to use in terms of effectiveness, low human toxicity and ease of handling. Application of borax is possible using a large saltshaker or a plastic bottle with holes on one side. Approximately 200 grams of borax per square metre of stump surface are required to achieve control. The secondary spread of *H. annosum* is much more difficult to control since it takes place underground. An antagonistic fungus, *Peniophora gigantea* (Fr.) Massee, is being used experimentally in Ontario but tests are not yet complete. This may provide a useful control measure in the future.

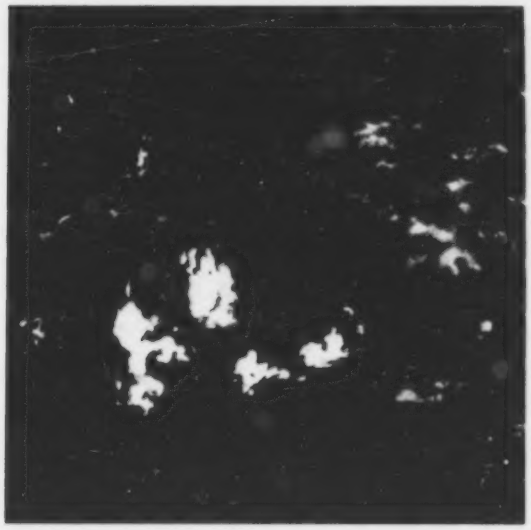


Figure 13. *Fruit bodies of Heterobasidion annosum at base of red pine.*

LOPHODERMIUM NEEDLECAST

Lophodermium pinastri (schrad.) Chev.

HOSTS AND DISTRIBUTION:

Lophodermium pinastri has been reported in British Columbia, Ontario, Nova Scotia and several states in the U.S.A. Many pines are attacked but red pine and Scots pine are the most important. The disease can be very damaging in nurseries where the relative humidity remains high for several hours each day.

SYMPTOMS:

Red pine needles become infected by ascospores in the summer and fall. Fungal colonization occurs throughout the winter under snow cover. By spring, yellowing and browning of the needle tissue is apparent. Brown spots with yellow margins form on the needles and fruit bodies are produced by fall (Fig. 14). The ascocarp is a two to three millimetres long, shiny black with a football-shaped structure. In moist weather a slit in the fruit body opens and the spores are released. The spores are spread by rain splash and wind to nearby trees which then become infected if conditions favour spore germination.

CONTROL:

Early detection of *Lophodermium pinastri* is most important. If 20 percent or more of the tree foliage is brown in May or June, a spray program should be undertaken to prevent infection of a future crop. Daconil 2787 has received Canadian registration and is recommended for use on conifers in nurseries. Spraying should begin in July or August and be repeated at three-to-four week intervals until late September. The spray mixture should contain about 0.3 percent chlorothalonil. Full foliage coverage is essential. The number of sprays and the length of spray program will largely depend on the climatic conditions present in any given year.

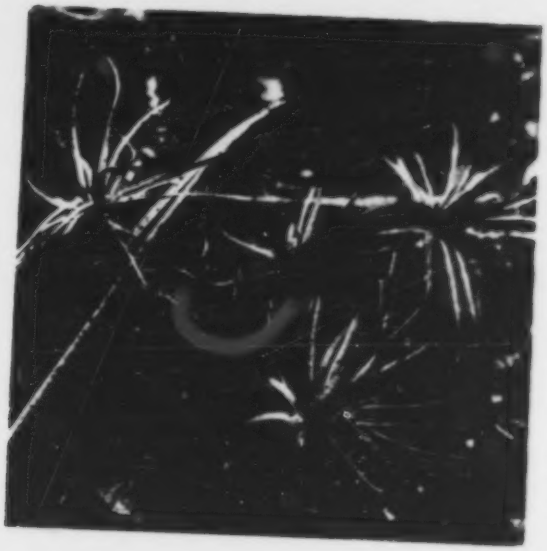


Figure 14. *Black fruiting bodies of Lophodermium pinastri on red pine needles.*

SCLERODERRIS CANKER

Gremmeniella abietina (lagerb.) (=Scleroderris lagerbergii Gremmen)

HOSTS AND DISTRIBUTION:

Gremmeniella abientina or Scleroderris canker has been found in Ontario, Quebec, New Brunswick, Newfoundland and Nova Scotia. The principal hosts are red, Scots, white and jack pine, and white and black spruce. Strains of the fungus which differ in their pattern of host attack and host range exist. The European race of *G. abientina* is present in eastern Canada but has not as yet been found in Ontario. The North American race, however, does occur in the province and is subsequently discussed.

SPREAD:

In the first year of the life cycle, fungus spores deposited on pine needles or buds will germinate if favourable environment conditions exist. Fungal growth spreads through the buds, needles, branches and main stem. This continues throughout the first winter and by spring the needle bases appear reddish-orange. During the following summer, fall and winter, fungal development results in the formation of a main stem canker. Where stem girdling occurs, trees often die. Asexual spores are produced; they are responsible for spreading the disease locally or from one part of a tree to another. Sexual spores are also produced; they are carried by the wind thus facilitating long-range spread.

SYMPTOMS:

One diagnostic symptom of *Gremmeniella abietina* is the reddish-orange discoloration which occurs at the base of the needles in the spring (Fig. 15). These needles bend down and by summer, turn brown. Entire branches may die, especially those low on the stem. Cankers can be seen on older infected trees. If the bark is removed from the canker, greenish discoloration may be evident. Light brown fruit bodies (apothecia) form on the branches in the spring.

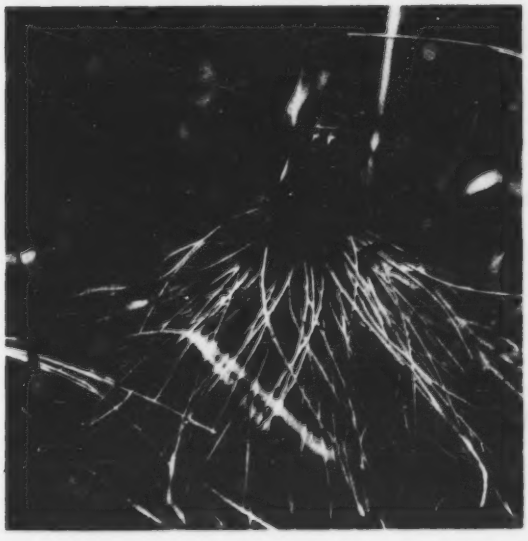


Figure 15. *Red pine needle discoloration caused by Gremmeniella abietina.*

CONTROL:

Scleroderris canker can be controlled in the nursery by spraying with chlorothalonil. An early spring spray, just as the needles begin to form, followed by sprays at two-week intervals until mid-June and thereafter at three-to-four week intervals until the end of August, will control the disease. In plantations, all sources of inoculum should be eliminated. This usually involves pruning and burning the infected branches up to a two-metre height.

ARMILLARIA ROOT ROT

Armillariella mellea (Fr.) Karst. (= *Armillaria mellea*)

HOSTS AND DISTRIBUTION:

Armillaria root rot is common in the forested areas throughout world temperate and tropical regions. The fungus is found on hundreds of woody plant species. Most of Ontario's forest, shade and fruit trees are susceptible, especially when host vigour is low.

SYMPTOMS:

Armillaria root rot symptoms vary according to the host plant; but in general there is a decline in growth, premature yellowing, and loss of undersize foliage. Branches die back and trees eventually die. As the wood in the root-collar area becomes decayed, white mycelial fans of the fungus appear under the bark. In addition, dark brown or black rhizomorphs are found between the bark and wood or on the outside of roots. When the decay is advanced, clusters of honey-coloured mushrooms develop at the root collar or on roots that are near the soil surface in the fall (Fig. 16). The rotted wood is light brown to yellow white and usually has many black zone lines.

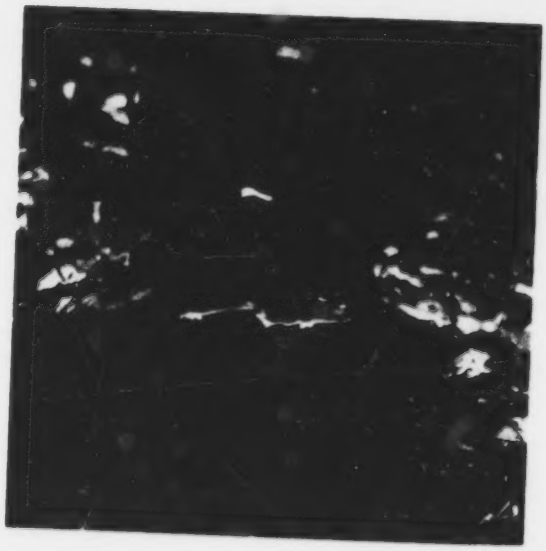


Figure 16. *Armillariella mellea mushrooms on red pine stump.*

SPREAD:

Infection by *Armillariella mellea* usually occurs when underground rhizomorphs penetrate unwounded roots. Infection may also occur through root contacts. After extensive root decay, the host is killed and the fungus assumes a saprophytic role. It may remain active in the soil debris for many years, thus making plantation establishment difficult.

CONTROL:

From a practical standpoint, very little can be done to control Armillaria root rot in red pine plantations. The best control is to maintain vigorous plantations by good species – site selection.

RED PINE DECLINE

HOSTS AND DISTRIBUTION:

Red pine decline has been reported in Ontario and in the northern United States. There is no single organism that causes this problem but rather a series of factors which contribute to decline.

SYMPTOMS:

The general symptoms include chlorotic needle tissue in the upper crown, tufted foliage at the branch tips, needle browning, and tree death (Fig. 17). The fine roots are often blackened or completely absent or cortical lesions have been observed on the larger roots.

Several factors contributing to decline are:

(a) Red pine requires moderately to well-drained sites. Excessive and poorly drained sites often cause red pine decline.

(b) Pastured soils do not generally support trees with red pine decline, but cultivated soils often do. This appears to be related to moisture, micro-relief and depth of litter.

(c) Soil depth for rooting must be adequate.

(d) Red pine is best suited to acid soils. The species may, and frequently does, fail on alkaline soils.

(e) The presence of excess calcium reduces the availability of other elements even if they are present in sufficient quantities. Therefore, the possibility of lime-induced deficiency of manganese and/or iron exists.

CONTROL:

Decline in red pine is not usually evident until the trees are 20 to 35 years old. Visible symptoms and changes in the site index occur only after extensive damage to the root system. Affected trees will generally not respond well to increased crown space so thinning is not a cure. Proper site selection before planting is probably the most important factor in eliminating this problem. Moreover, pathological problems may be reduced if proper species – site selection is made. This would help to eliminate the adverse growing conditions which may predispose trees to fungal infection and insect attack.

Figure 17. *Chlorotic symptoms and tufted condition characteristic of red pine decline.*

RED PINE NEEDLE RUST

Coleosporium asterum (Diet.) Syd.

HOSTS AND DISTRIBUTION:

Coleosporium asterum or pine needle rust is found throughout Canada and the United States. Most of the two and three needle pines are affected. Red and jack pines are the major tree hosts in Ontario. The alternate hosts are goldenrod and aster.

SYMPTOMS:

Small trees heavily infected by *Coleosporium asterum* often show a decline in growth but are rarely killed unless this disease is combined with another that kills current-year foliage. A white-to-yellowish, blister-like structure develops on the one-year-old needles (Fig. 18). Later this aecial structure ruptures and releases orange-coloured spores. These spores infect the alternate hosts in the summer and by fall, spores produced on the alternate hosts are capable of infecting the pines. Needle symptoms develop the following spring.

CONTROL:

Although no practical control of *Coleosporium asterum* is known, elimination of the alternate hosts by herbicide spraying will help to reduce the number of spores available for infection.

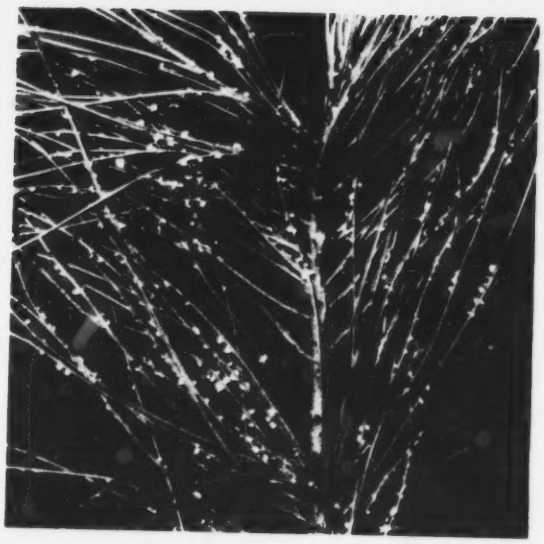


Figure 18. *Coleosporium asterum fruiting on red pine needles.*

Vertebrate Pests

Several vertebrates may threaten the success of a plantation by browsing the foliage, destroying the buds, clipping the twigs, or stripping bark from stems and branches. These may be classified into two principal groups; the rodents, or gnawers, and the ungulates (hoofed animals), or browsers. Potentially, members of either group may be highly destructive to young tree growth where wildlife and forest management are not coordinated. In addition, there are a number of miscellaneous vertebrates, mainly birds, which inflict occasional injury.

MICE

Mice, especially the field mouse or meadow vole, often cause serious injury to young pines by gnawing the bark near the root collars and the trunk as high up as matted vegetation or snow cover provides concealment. Close examination of the injury reveals paired marks left by incisor teeth with tiny ridges of bark remaining between the cuts. These tooth scars may run at all angles even on small branches. Small trees up to seven millimetres in diameter are frequently gnawed through. Damage is greatest in years when the snow is deep and other winter food scarce. Injury may become apparent in the spring soon after the snow melts and tree growth starts. Its full extent, however, cannot usually be assessed until the following autumn because many of the girdled trees do not die immediately. Damage by mice is most likely to take place during the first 10 years in the life of the plantation. Injury during the first winter after planting usually results in tree mortality. Older trees usually die when they are girdled more than three-fourths of the way around their circumference. Older trees less than half girdled may resume their normal growth rate within three years.

Frequent inspection of young plantations is important, particularly from late August to November. A mouse population of 250 per hectare is likely to result in extensive feeding on trees. Control mainly consists of applying cracked corn treated with zinc phosphide or warfarin placed in late fall at bait stations or in feeding cylinders strategically located in the runways. Stations are used rather than broadcasting the pest-control substance over the plantation's ground surface in order to lessen the hazard to non-target animals. A border area surrounding the plantation should also be treated to prevent migration from neighbouring fields. Chemical repellents will also reduce the damage; but since they are primarily taste repellents, they will not entirely prevent damage. The need for chemical poisoning may, however, be obviated by cultural practices such as good grass and weed control. This reduces the area's suitability for mouse habitation and gives predators a better opportunity to control the rodent population. Rotary mowing is better than sickle-bar mowing as it doesn't leave a mulch beneath which mice can reproduce.

RABBITS

At least two species of rabbits or hares feed on the bark, buds or needles of conifers during the winter. Bark feeding usually occurs low on the stem, exhibiting characteristic horizontal tooth marks about three millimetres wide. Young trees are sometimes seriously damaged but larger trees are seldom affected. Damage becomes most evident in mid-to-late summer when whole trees turn red. Rabbits vary in number from year to year but hare populations fluctuate according to regular cycles of 10 to 11 years. The buildup of large populations is prevented by eliminating brush piles and by hunting. The use of wire or plastic stem sleeves or small-mesh fencing is impratical in a forest plantation but may be economically feasible for protection of high-value plantings. Chemical repellents, such as thiran, are effective only if the population pressure is not too severe in relation to availability of alternate food.

PORCUPINES

Red pine is one of many kinds of trees fed on by porcupines, when herbaceous plants are not available. Complete girdling of the bark usually results in the death of the tree. Further, even spot damage may seriously affect growth and timber value. Feeding on a pole-size tree often occurs in the upper fourth of the main stem. The tree may not die; instead it becomes spike-topped, making it quite useless for lumber, and its appearance is unattractive in recreational areas. The porcupine often chooses the dominant and thriftiest trees on which to feed, leaving the suppressed and poorer ones to perpetuate the stand. Sparse populations of porcupines are the rule. They are, however, colonial part of the year with several individuals sheltering in dens located in hollow trees or caves among rocky outcrops. Hence, damage in plantations established in such environs may be concentrated but sporadic. The porcupine has few natural enemies. Shooting or trapping, and removal of den trees or blocking of caves, are the most practical methods of control.

SQUIRRELS

Injury to red pines by squirrels consists mainly of wounds created when the deeply attached cones are torn from the twigs. Injury occurs early in fall while the cones are still green, and the squirrels collect and cache them in the ground or hollow logs as a source of winter food. Often the twig beyond the wound will die resulting in red flags the following spring. Control is usually not necessary since damage is seldom repeated the following year. The red squirrel is generally more common and destructive than the black or gray squirrel. Injury resulting from the activities of the chipmunk is of negligible consequence.

GROUNDHOGS

Young trees, newly outplanted on land with clovers or alfalfa in the ground cover, are often destroyed by groundhogs or woodchucks if planted within 10 metres of the several entrances

to their burrows. Once established, however, trees are rarely injured. Damage to trees occurs mainly in the spring as the groundhogs wear down their incisor teeth after hibernating. Hunting is the best control measure.

DEER AND CATTLE

Deer-caused injury to red pines is relatively insignificant. Bud browsing result in a nearly square cropping of the end needles surrounding the bud. Abrasion of the bark from antler polishing to remove the velvet in early fall is of no consequence. Cattle rarely graze pine foliage when other green foliage is available; but mechanical injury from trampling and breaking may occur if pasturing is permitted the first few years after planting. Exclusion of cattle, and to a lesser extent deer, is accomplished by fencing.

BIRDS

Several species of birds eat red pine seed. Some, such as the pine grosbeak, occasionally feed on the buds, destroying the meristem and stunting or deforming the lineal growth. Heavy feeding may result in spike tops or "witches'-brooms" depending upon the extent of the destruction and the growth reaction of adventitious buds.

Attacks by the yellow-bellied sapsucker occur but are not as common on red pine as on Austrian pine, hemlock, and several species of broadleaved trees. This migratory member of the woodpecker family feeds extensively on insects but attacks living trees to feed on the sap, inner bark and cambium. Pencil-sized holes are drilled through the bark in a characteristic lacework pattern and are periodically enlarged. The puncture wounds along with the subsequent sap flow on the trunk and branches are the most obvious symptoms of injury. The openings may serve as entry courts for wood decay or stain fungi and bacteria. The wounds may also attract porcupines or red squirrels that could further injure the tree when feeding. After repeated attacks on the same area of a tree, large patches of bark may be removed. If this area is girdled, the portion of the tree above this point could die. Protection from birds on a plantation basis is impractical and unnecessary.

VI. TENDING

Cleaning

Red pine grows best in full sunlight, so complete release of red pine seedlings from shrubs and fast-growing hardwoods, such as poplar, is necessary. Hand release or release using a herbicide spray may be used.

Pre-commercial Thinnings

Provided that a plantation has been planted at the proper spacing, there should be no need for pre-commercial thinnings. However, there may be some instances where such thinnings are necessary. An example would be if red pine is in mixture with another species, and the other species is unlikely to reach commercial value. It is then advantageous to remove this species, at least in part, and in so doing provide access for future thinnings.

In situations where it is evident that stands are developing poorly due to site conditions, close spacing, etc., pre-commercial thinnings may be advisable in order to stimulate growth of the residual trees.

Every effort should be made to market the thinned material.

Commercial Thinnings

Thinnings in all plantations must be scheduled so as to produce maximum growth of good quality residual trees and thus produce the most revenue over the life of the stand.

Planning for thinning is influenced by operational difficulties, tree size and species mixtures. This planning must also pay specific attention to the types, quantities and values of products removed in the thinnings. The locations of skid roads and landings require careful consideration as these may not have been adequately planned during stand establishment. Finally, the composition of the residual stand should be clearly established.

First Thinnings

The first product removed from plantations is usually pulpwood. Present specifications call for average trees to contain at least two 2.5 metre pieces with minimum small-end diameters of 9 centimetres. These specifications are usually attained by trees approximately 25 years old.

All subsequent thinnings are very much influenced by how the first thinning is accomplished. The operating difficulties of felling and skidding usually limit first thinnings to the mechanical removal of rows of trees.

Row thinning allows for the easy establishment of access trails and landings, which can then be used during later thinnings. Its major disadvantages are the loss of some potential crop trees and loss of even distribution of growing space. The latter disadvantage is especially evident when adjacent rows must be removed. In order to lessen the disadvantages, a general rule of thumb is to remove the least number of rows and still provide the requisite access.

The combinations of numbers of rows to be removed or left are too numerous to make an evaluation here, but rather a few proven methods which may be used in various stand conditions are outlined as follows.

PURE RED PINE STANDS

Red pine is the most favoured species for pulpwood in central and southern Ontario. A pure stand is probably the easiest to thin; products are readily marketed; and a number of thinning options are possible.

In most plantations, adjacent rows should not be removed. If a sufficiently wide working area is provided with the removal of one row, it is then advisable to remove every fourth row, leaving three adjacent rows for a second selective thinning (Fig. 19). If the desired width of working area is not provided with one-row removal, it is then necessary to remove two adjacent rows. In this case, it is currently recommended that the adjacent rows be left for the second (selective) thinning.

Figure 19. *Thinning Regime: A 35-year-old plantation at 2.1 m x 1.8 m spacing. Row thinned one in four at age 27, it is ready for a second thinning. (Strachan Tract, Simcoe County Forest.)*

STANDS WITH TOPOGRAPHIC RESTRICTIONS

Regardless of species content or tree quality, it is sometimes impossible to conduct row thinnings if the rows run parallel to steep slopes (Fig. 20). In such cases, it is necessary to thin in the direction of the slope and approximately perpendicular to row direction. Again, as few as possible of the "crossrows" should be removed in order to minimize the loss of uniform growing space, yet provide adequate access. Crossrows should be kept as narrow as possible and still provide adequate working space.

In most plantations, spacing within rows will necessitate the removal of at least two adjacent trees except where gaps occur due to mortality. Advantage should be taken of these gaps and so minimize the removal of adjacent trees.

Crossrow thinning does provide the opportunity for limited selection. Nonetheless, strips must be cut straight enough to allow for skidding without damaging the residual stand.

Figure 20. *A 46-year-old red pine plantation strip, thinned across the original rows and against the sloping topography at age 37. Original rows run left to right. Trees are 18 m tall. (South Barr Tract, Simcoe County Forest.)*

STANDS WITH SPECIES MIXTURES

Stands that include one or more species other than red pine are probably the most difficult to manage. Many are growing on excellent sites; they have potentially high-value trees other than the red pine and, therefore, deserve attention.

White pine is most commonly found associated with red pine in plantations. Other species include white spruce (*P. glauca* (Moench) Voss), European larch (*L. decidua* Mill.), Scots pine and jack pine (*P. banksiana* Lamb). Regardless of the content of these associate species, their importance as continuing stand components must be considered before the first thinning is carried out.

In some cases, the associate species will be so suppressed at first thinning that they may be considered as little more than a hindrance. Their mortality may, in fact, be considered as a first thinning and the space they previously occupied will usually provide the necessary access for subsequent thinnings. In such cases, the cutting schedule should probably be postponed until a second selective thinning is necessary. At that time any of the associate species still alive may by knocked down and disposed of as simply as possible.

When associate species are competing successfully with the red pine and are important as potential seed trees or forest products, every effort should be made to maintain them as components of the stand. There are numerous combinations of rows of red pine with rows of associates that may constitute the first thinning. The difficulty with associate species such as white pine and white spruce are that few markets currently exist for small trees of these species. Moreover, because of their branching characteristics they are difficult to fell and limb. It may be necessary then, on account of market considerations, to remove a large percentage of the red pine component. Alternately, some rows of associates should be removed even at a reduced stumpage.

The most common association found in plantations is red and white pine in alternate rows. Very often there is a significant number of white pine, which would form a valuable stand component if released early. Ideally, the best thinning method would be the removal of alternate rows of white pine thus leaving three adjacent rows, two of red pine and one of white pine. The remaining white pine may then be released by later thinning. This method ensures maximum utilization of the red pine and the opportunity to manage the remaining white pine.

The difficulty will be in finding the markets for the first white pine thinnings. If markets are limited, it may be necessary and justified to expend tending funds to ensure that thinnings are carried out on time. This expenditure should, of course, be avoided if possible.

Second Thinnings

Second thinnings will again produce pulpwood, and possibly small poles and sawlogs. It is likely

these products will have a pulpwood unit value or slightly higher.

Operating restrictions will require that a large percentage of stems be removed, up to 50 percent, especially if pulpwood is to be produced. Silviculturally, it is desirable that all poor quality stems be removed during this thinning. This leaves only the best trees to develop and produce high-value products, which will be removed in later thinnings. Trees to be removed are those having poorly developed crowns, poor form, are suppressed and those which have been damaged by storms and wildlife activities.

Regardless of the first thinning method used, it should be possible to apply a selective method in succeeding thinnings. Extreme topographic conditions are the only situations when it may be necessary to use the row or crossrow method in a second thinning.

Crossrow thinnings have been conducted in the past as an alternative to the removal of adjacent rows, especially when such removal would result in only one row or two adjacent rows being left. With the acceptance of selective thinning in young plantations, this alternative would seldom be used.

Second thinnings are usually conducted approximately five years after the first thinnings. This time interval is variable and will depend on crown and stem development since the first thinning.

There are a number of methods used to determine when stands are ready for a second thinning. One method commonly used is the determination of an acceptable minimum basal area/hectare. If residual basal area is within an acceptable range of square metres per hectare after removal of a required volume, a decision may be made to thin. If the subsequent basal area were to fall below acceptable limits, then thinning would be postponed. It is generally agreed that the residual basal area after second thinnings should not be less than 23 square metres per hectare.

It is important to protect potential seed trees during this thinning. They will not likely be a consideration at this time in stands in pure red pine; however, they should be considered when second thinning stands that have a white pine component. Even if only 10 to 20 potential seed trees per hectare are present, they should be protected and released during the second thinning.

Post Second Thinnings

With the completion of a second thinning, the following stand conditions should have been accomplished:

- adequate access roads, trails and landings established
- removal of all or most poor quality trees
- release of potential crop and seed trees
- relatively easy felling of all remaining trees ensured

Figure 21. *A 52-year-old plantation after three thinnings. The first thinning removed every fourth row at age 35. The middle row was removed at age 40 and the remaining trees were selectively thinned at age 50. Trees are 21 m tall. (N. Barr Tract, Simcoe County Forest.)*

A reliable thinning schedule for all further thinnings may now be set up. The products will be of high value and should find a ready market. Although a third thinning of pulpwood may be necessary, third and subsequent thinnings usually produce utility poles and sawlogs.

Heavy, early thinnings in plantations promote the retention of live lower branches and reduces the potential for maximum volume production. If utility poles are to be produced in later thinnings, early thinnings should not remove more than 33 percent of the basal area in a single cut. The first two thinnings may be five years apart, with subsequent thinnings eight to ten years apart. In addition, no thinning should reduce the Stand Density Index (SDI) below the 507 level (Fig. 23). Using these criteria in the management of a sufficiently stocked stand (preferably with an initial stocking of 4000 or more trees per hectare), branch diameters should be acceptable for utility poles. Thinnings to higher levels of SDI will provide more total volume production.

Average stand diameter together with basal area and stems per hectare have proved useful in prescribing selective thinning operations. The percentage of stem removals should exceed that of basal area removal so that residual stand diameters are increased. This type of thinning

is sometimes referred to as "thinning from below". As a general guide, residual dbh should exceed original dbh by not less than:

- 1.2 centimetres for stands up to 22 centimetres dbh, and
- 0.8 centimetres for stands 22 to 36 centimetres average dbh

Figure 22. *Aerial view of a 36-year-old plantation of red and white pines showing two-row thinning regimes (1 in 3 and 1 in 4). Note access road and protection lanes in the younger plantation in background. (Bruce County Forest.)*

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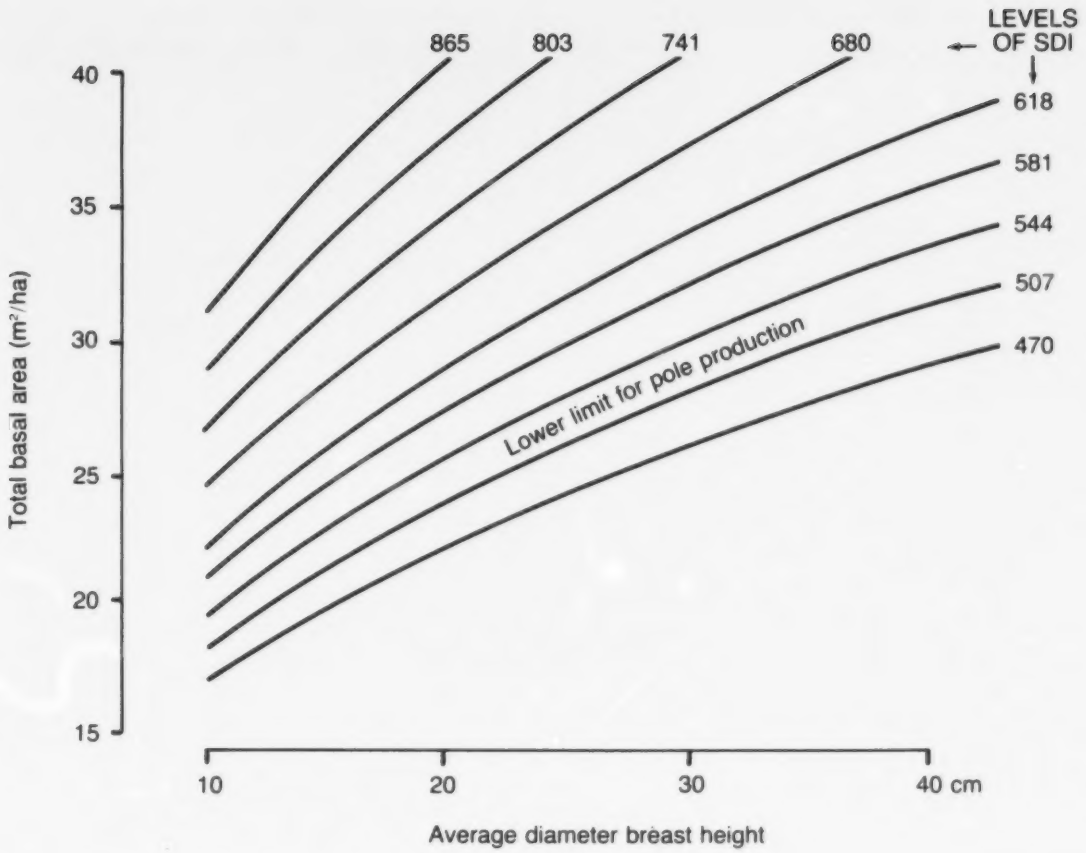


Figure 23. Thinning guide to stand density for pole mangement.

Storm Damage Considerations

Infrequent but severe ice and snow storms may cause damage to red pine plantations. For areas of the province where such storms are more common, good forestry practices which adhere to regular thinning schedules are the best insurance against damage. A study of a 1979 ice and snow storm (without wind) at Northumberland County Forest revealed that damage was correlated to the following: species, stand age, species mixture, stand density, type and degree of thinning, slope and topography.

Red pine is more susceptible to breakage than white pine but less susceptible than jack and Scots pines. Mixed plantations display greater resistance to damage than pure stands. This may be attributed to the uneven canopy produced by mixed species. The uneven canopy reduces the chain reaction on the entire plantation when trees are broken off and fall into each other (domino effect). Plantations up to 15 years of age are less affected than older stands. Younger stems exhibit the flexibility to withstand ice and snow load breakage.

Figure 24. *Ice and snow storm damage in a 38-year-old stand six years after an alternate row thinning was done in this previously overstocked stand. Note the domino effect down the hillside. (Northumberland County Forest.)*

Table 2: Minimum Residual Basal Area, Stocking and Spacing Following Thinning for Pole Production in Red Pine Plantations

Average dbh (cm)	Basal area/ha SDI 507 (m^2)	Trees/ha SDI 507	Average spacing SDI 507 (m)
10	17.6	2251	2.1
11	18.2	1932	2.3
12	18.9	1623	2.5
13	19.5	1478	2.6
14	20.1	1313	2.8
15	20.7	1175	2.9
16	21.3	1060	3.1
17	21.7	962	3.2
18	22.3	877	3.4
19	22.8	805	3.5
20	23.2	741	3.7
21	23.8	685	3.8
22	24.2	636	4.0
23	24.6	592	4.1
24	25.0	553	4.3
25	25.4	518	4.4
26	25.8	487	4.5
27	26.2	458	4.7
28	26.7	432	4.8
29	27.1	409	4.9
30	27.3	387	5.1
31	27.7	367	5.2
32	28.1	349	5.4
33	28.3	332	5.5
34	28.7	317	5.6
35	29.1	302	5.8
36	29.3	289	5.9
37	29.7	276	6.0
38	30.1	265	6.1
39	30.3	254	6.3
40	30.8	244	6.4

Currently overstocked stands are prime candidates for storm damage. Previously overcrowded stands that have been drastically thinned (i.e. up to 50 percent) may still be vulnerable to storm damage for six to seven years after thinning (Fig. 24). Row thinning (especially double row thinning) leaves the stand more open to damage than selective thinning. Topography and slope also influence the amount of damage to trees; hilltop trees are more exposed. Air currents may also distribute a heavier precipitation on hillsides. Broken trees on hillsides tend to fall downhill, contributing to a domino effect that results in total damage to an entire hillside. Plantations growing in storm-prone areas should be managed very carefully. The degree of thinning should be conservative, especially in overstocked plantations, and should not exceed removal of 25 percent of the basal area. Light and frequent thinnings are recommended over heavy and infrequent cuts.

The time interval between thinnings may again be determined by the establishment of a minimum residual basal area per hectare after each thinning, as described earlier. It is generally agreed that residual basal area should increase as the stand approaches maturity (Table 2). In almost all of these thinnings a selection method should be used.

During first and second thinnings, co-dominant and suppressed trees are usually removed, that is stands are thinned from below. Reliable economic analyses comparing thinnings from above and below are either not available or are impractical for use in the field. The decision to thin from above, below, or both can therefore be made only when stands are ready for thinning. This decision is dependent upon:

- market conditions at time of thinning, and
- distribution and quantity of dominant trees at time of thinning.

Markets fluctuate greatly within relatively short time periods, i.e. one or two years. If markets are particularly good at the time of thinning, it is advisable to thin from above as to take advantage of high stumpage values. This, however, may be done only if enough dominant trees are present to ensure an adequate supply of high value products from future thinnings. If prices are stable or poor at the time of thinning, it is advisable to thin from below in order to save high quality trees until markets improve, but still reduce basal area and so increase growth on the high value trees.

Pruning

The selection and pruning of crop trees should be carried out only in stands growing on the better site classes (that is: site classes 1 and 2), and where active plantation management practices such as regular thinnings are being carried out. A thinning regime must be determined and recorded before crop trees are selected in order to eliminate the possibility of removing crop trees in subsequent thinnings. Crop tree selection should be based on the following criteria: The tree should be a dominant or co-dominant tree, exhibiting a well-developed leader and a

full, round, finely branched crown, straight diameter and no stem injury of any kind.

Up to 370 trees per hectare should be pruned during the polewood stage when diameters range between 10 and 15 centimetres. First pruning should be coordinated with and precede the first thinning. Second stage pruning should take place five to ten years later or at the time of the second thinning. The branches should be cut as close as possible without cutting into the branch bark ridge and the branch collar (Fig. 25). Ideally, pruning should not exceed half the total tree height. Pruning any more than this will cause a small, temporary reduction in growth; but it may be justified where economics dictate that one log-length be pruned in one operation. Pruning should be carried out to a height of 5.1 metres in a two-stage operation (Fig. 26). Pruning to this level improves the quality of red pine for sawlog or veneer production. For pole specifications pruning should be carried out to a height of 7.4 metres.

Figure 25. Pruning: A red pine tree pruned to 5.1 m. This 59-year-old plantation averages 21 m in height. (Hendrie Main Tract, Simcoe County Forest.)

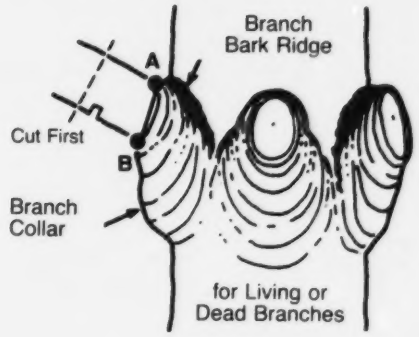


Figure 26. *Pruning technique:*

1. Locate the branch bark ridge (BBR).
2. Find Target A – outside BBR.
3. Find Target B – where branch meets collar.
4. Stub cut the branch.
5. Make final cut at line AB (with powersaws make final cut on upstroke).

Do Not:
- ☐ make flush cuts behind the BBR.
- ☐ leave living or dead stubs.
- ☐ injure or remove the branch collar.

The best time to prune living branches is late in the dormant season or very early in spring before leaves form. Dead and dying branches can be pruned anytime. Use sharp tools. Make clean cuts.

Courtesy U.S.D.A. Forest Service – A. L. Shigo

Fertilization

Fertilization and growth response is a complex topic where few definitive answers exist at this time. Fertilizing is not common and it is not likely to be recommended unless red pine growing on a particular site which has a major nutrient deficiency.

Before any operational fertilization is conducted, a careful preliminary study employing foliar analysis is required. Following fertilization, the trees should be closely monitored and follow-up treatments applied in order to maintain a healthy nutrient balance in the tree. This nutrient balance may change and, as a result, further fertilization adjustments may be necessary. Past experience has shown that too much of one nutrient after the tree has adjusted to a new nutrient balance may kill the tree.

VII. GROWTH AND YIELD

Growth data have been collected on permanent sample plots by the Canadian Forestry Service at the Petawawa National Forestry Institute and on regional forests managed by the Ontario Ministry of Natural Resources. The data from Petawawa cover unthinned plantings made at spacings differing from 1.2 m x 1.2 m to 4.3 m x 4.3 m and from 9 to 53 years of age. Growth data collected by the Ontario Forest Research Centre cover thinned and unthinned stands planted at 1.83 m x 1.83 m or less from the time of first thinning onward.

Volume scaling and stem analysis information is also available from numerous sample trees cut during thinning operations.

These data have provided the base for a site-index table, a standard-volume table and several yield-and-growth tables up to 50 years of age.

Spacing Effects in Red Pine Plantations

Spacing is defined herein as the distance between seedlings when they are planted in the field. This planted spacing markedly affects the development of the individual tree as well as the stand. The effects are similar whether the spacing arrangement is rectangular (when the distance between rows is different from that between the trees in a row) or square (when these distances are about equal). The latter arrangement is assumed here for the sake of convenience. Spacing, an expression of stand density (numbers of trees per unit area), is commonly used because it is more readily visualized. The relationship is shown in Table 3 for two spacing-class intervals.

The square of the spacing is the area allotted to each seedling (such as 4 m^2 for 2 m x 2 m), and represents the growing space available to it. The smaller the space, the sooner the young tree occupies it and comes into competition with its neighbours. Above ground, the direct effect of spacing is on the crown, controlling its length and width, the thickness of its branches and the mass of its foliage.

The indirect effect of spacing, reflected in the crown development and response, is on stem development. Simply, the more foliage there is, the greater the photosynthetic production and the more wood is laid down in the annual ring. In terms of stem diameter, wider spacings give greater diameters at breast height (Fig. 27). Since the greater proportion of wood formed seems to be laid down on that part of the bole within the live crown, the longer crowns resulting from wide spacings are accompanied by more tapering stems; conversely the shorter-crowned trees found at close spacings tend to have more cylindrical stems. Height is little affected by spacing, although, at the extremes of very high and very low densities there may be some reduction. In practical silviculture, for the spacings likely to be planted, the effects on height are probably negligible.

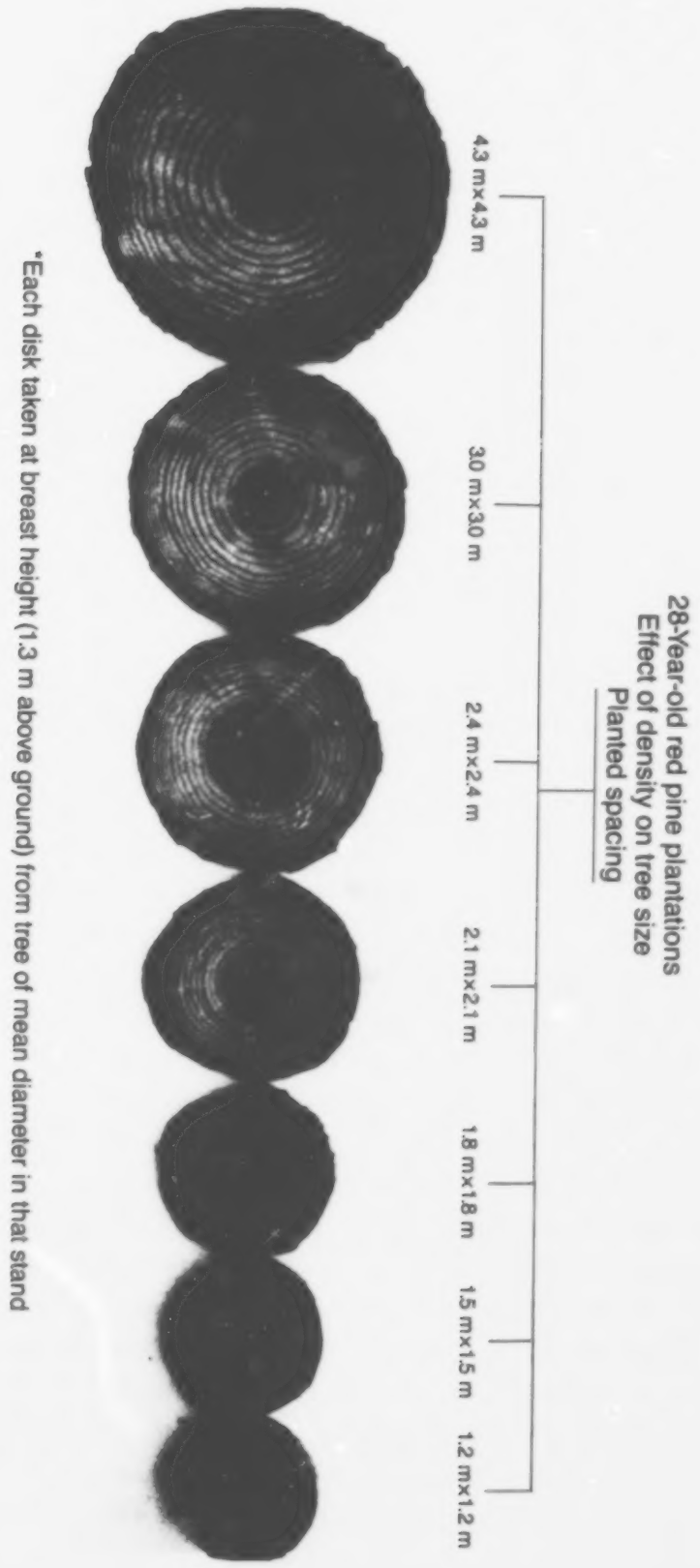

28-Year-old red pine plantations
Effect of density on tree size
Planted spacing
4.3 m×4.3 m
3.0 m×3.0 m
2.4 m×2.4 m
2.1 m×2.1 m
1.8 m×1.8 m
1.5 m×1.5 m
1.2 m×1.2 m
*Each disk taken at breast height (1.3 m above ground) from tree of mean diameter in that stand

Figure 27. *Diameter growth: Breast-height sections of 28-year-old red pine trees planted at seven spacings show effect of density on tree size. (Photo courtesy of the Canadian Forestry Service.)*

Branch thickness has implications concerning the production of knotty wood and lumber quality, which would be minimal for trees planted 4.3 metres apart. In particular, branch (knot) thickness affects the utilization of trees for poles. The Canadian Standards Association's specifications for red pine poles do not allow the aggregate knot diameters in any 0.30 metre section to exceed 200 millimetres for poles 14 metres and shorter or 250 millimetres for poles 15.5 metres and up. Wide spacing permits branches to live longer and, hence, become thicker before being shaded out. Measurements made in a red pine spacing trial where trees were about 18 metres tall, suggested the following relationship for high survival plantations of that height class:

Table 3: Measurements from a Red Pine Spacing Trial

Planted spacing (m)	Percentage of Trees disqualified as poles*	
	<14.0 m	>15.5 m
2.00 x 2.00	0	0
2.25 x 2.25	5	0
2.50 x 2.50	20	0
2.75 x 2.75	34	0
3.00 x 3.00	47	0
3.25 x 3.25	60	7
3.50 x 3.50	73	14
3.75 x 3.75	87	20
4.00 x 4.00	100	27

*Sum of branch basal diameters in any one whorl exceeds the allowable 20.3 centimetre maximum to qualify it for a pole.

Red pine in roundwood form is mainly used as poles or reinforcing stubs. Tables 23 and 25 give dimensions of poles and stubs. Tables 22 and 24 indicate the utilization for these various products from trees of different size classes.

In terms of stand development, full utilization of the site occurs sooner at closer spacings; the total stem volume per hectare is always higher. Stands growing at wide spacing may never make up the volume difference even though their growth per hectare after crown closure may be greater. In addition, at wide spacings, merchantable volume per hectare — that is trees of pulpwood size — becomes more equal, and sawlog volume will be larger. Another biological phenomenon affected by spacing is the cone crop. A good crop requires large crowns, so for seed orchards wide spacings are employed. Close-planted red pines are vulnerable to breakage from snow or ice storms before merchantable sizes are attained.

In summary, a wider spacing will result in trees with longer crowns, thicker branches, greater diameters at breast height and more stem taper (Fig. 28). However, the total volume per unit area will be lower. To grow pulpwood, a closer spacing is indicated; to grow sawlogs, a wider

Figure 28. *Early plantation development: This 25-year-old plantation planted at 2.1 m x 1.8 m spacing is ready for its first thinning. Height is 13 m. (Strachan Tract, Simcoe County Forest.)*

spacing; and for cone production a wider spacing yet.

Spacing effects are dynamic, changing with time and tree size. Since closer spacing leads to earlier competition, this means not only earlier mortality of the lower branches but of whole trees as well. Therefore the process of self-thinning by natural suppression begins earlier at closer spacings. There is a definite mathematical relationship between stand height and the number of trees per unit area which defines when this self-thinning begins, and can therefore be predicted. For red pine, $\bar{H} = 2.05 + 12091.7345/X$, where X is the initial number of trees per hectare and $\bar{H}$ is the mean height in metres (height of tree of mean basal area) at which mortality begins. In other words, what is a "wide" spacing when the stand is only three metres tall may be considered "close" when it is ten metres tall, because of the intense competition which will prevail at that combination of height and tree numbers. Deferring thinnings in close-spaced plantations causes real problems when felling and extraction take place.

Tables 14 through 18 show the development of high-survival, unmanaged red pine plantations from ages 20 to 60, for eight planted spacings and five site index classes. These tables were developed from permanent sample plot data and can be entered if age and dominant height are known. Dominant height (H) is the average of the tallest 10 percent of trees in metres, and can be estimated from the height of the tree of mean basal area ($\bar{H}$) with the equation $H = 0.5089 + 1.1140 (\bar{H}) - 0.00364 (\bar{H})^2$. Bracketed values in tables indicate extrapolations beyond the range of the original data. These yield tables represent the highest stocking that can reasonably be expected for a given planted spacing. While it may be difficult to match such high yields except in small areas, the potential has been identified, and comparative performance for various stand parameters at different spacings has been illustrated.

Volumes of Individual Trees

Total stem wood volume (m^3) for individual red pine may be found from the standard volumes in Table 20. The table or equation may be entered if dbh over bark and total height of the tree are known.

Projected Yield – Red Pine Plantations

The volume yield of forest stands has classically been estimated with the use of normal yield tables. A more flexible method, which is more readily applicable to managed stands, is the use of variable density yield tables. A set of such tables has recently been published for red pine plantations in Ontario by Beckwith, Roebbelen and Smith. These tables may be used to evaluate the yields from various thinning regimes for a plantation up to age 65. They may also be used to compare yields resulting from thinning operations to yields obtained in unthinned stands.

The tables estimate gross total volume growth and basal area growth over a range of thinning levels (percentage of present stand) and give the corresponding yields five years after a prescribed treatment has taken place. They may be entered when the site index, age and either the present basal area or volume of a plantation is known. For further information on how to determine stand attributes see Tables 4 and 5.

Site Index

The dominant height attained by a stand of red pine 50 years after planting defines the site

index of the plantation (Table 21). It is entered with the number of years since planting and the corresponding dominant height of the stand. Alternately, site index is presented in chart form in Fig. 33.

The age may be obtained either from plantation records or from actual counts of internodes or annual rings at stump height. The dominant height may be obtained by:

(a) using the mean height of the 100 tallest trees per hectare. This parameter may be estimated by measuring the height of a random sample of trees, constructing a frequency distrubution and calculating the average height of that proportion of the sample that would include the 100 largest trees.

(b) by calculating the mean height of 10 to 15 subjectively chosen dominant and co-dominant trees in the plantation.

Data Source and Analysis

The site index table and chart were based on dominant heights of 361 stand estimates made at various remeasurement periods on 87 permanent sample plots in red pine plantations located in southern Ontario.

The data were analysed following "Method 3" described by Curtis *et al*, 1974. Basically the method uses a stepwise regression of site index, dominant stand height and plantation age. Height/age curves were only used to obtain the actual site index value associated with each stand.

Site index is often used as an entering variable in growth and yield tables similar to those which follow.

Table of Present Stand Volume

Table 4 estimates the gross under-bark volume (m^3/ha) (including top and stump) for pure red pine plantations, where the stand basal area (m^2/ha) and stand dominant height (m) can be measured in the field. The table may be applied either to unthinned stands or to plantations that have been thinned at any time in the past. It is most suited for stands between 20 and 60 years of age that were planted at an initial spacing of 1.83 m x 1.83 m or less.

The following steps are required in order to estimate the present yield of a plantation:

(a) The stand basal area may be determined using a wedge prism (BAF of three or less) or from fixed area sample plots (0.04 hectares or greater).

(b) An estimate of the stand dominant height may be obtained as described earlier in this subsection.

(c) Enter the table at the closest appropriate basal area and height values and interpolate to determine the gross under-bark volume (m^3/ha).

Data Source

The data used consisted of basal area, stand dominant height and gross total volume estimates obtained from 393 plot measurements and remeasurements taken on 87 permanent sample plots. These were located in 15 forests in southern Ontario and at the Kirkwood forest in Blind River District of central Ontario. The measurements were fitted to the combined variable formula[1] using simple linear regression.

Normal Yield—Unthinned Stands

Table 5 may be applied to red pine stands planted in initial spacings of 1.83 m x 1.83 m or less that have never been thinned. When the age and site index of such a stand have been determined, the following parameters may be estimated:

- number of stems per hectare,
- stand basal area (m^2/ha),
- mean diameter (cm),
- gross total under-bark volume (m^3/ha),
- dominant height of stand (m).

In addition, the table may be used to compare the yields of such stands with yields that may be obtained by thinning, as well as determine the stocking level of a thinned or unthinned stand. To do so, the estimated basal area of a particular stand is compared with the basal area found in this normal yield table for unthinned stands and the result expressed as a percentage of the latter. Estimates of five-year growth in any of the parameters may be found by taking differences between successive cells in the table.

1. S.H. Spurr, Forest Inventory, New York, 1952.

Table 4: Present Yields for Red Pine Plantations*†

Stand dominant height (m)	Gross total volume (m^3/ha) Basal area (m^2/ha)											
	15	20	25	30	35	40	45	50	55	60	65	70
8	**51**	**70**	**89**	**108**	**127**	**146**	**165**	**184**	**203**	**222**	**241**	**260**
10	65	89	113	136	160	184	208	231	255	279	302	326
12	79	108	136	165	193	222	250	279	307	336	364	393
14	94	127	160	193	227	260	293	326	359	393	426	459
16	108	146	184	222	260	298	336	374	412	450	487	525
18	122	165	208	250	293	336	378	421	464	506	549	592
20	136	184	231	279	326	374	421	468	516	563	611	658
22	151	203	255	307	359	412	464	516	568	620	673	725
24	165	222	279	336	393	450	506	563	620	677	734	791
26	179	241	302	364	426	487	549	611	673	734	796	858

* Based on the following combined variable formula:

$V = -6.0027 + 0.4745 (BA \times H)$

where V = gross total under-bark volume (m^3/ha)
BA = stand basal area (M^3/ha)
H = stand dominant height (m)
Standard error 7.3632 m^3/ha R^2 0.9957

† Ontario Ministry of Natural Resources, *Forest Research Report No. 108* Toronto, 1983), p.2.

Table 5: Normal Yields for Unthinned Red Pine Plantations*

Age (a)		Site index† 16	18	20	22	24	26
20	stems/ha	2776	2817	3023	3243	3402	3474
	ba (m^2/ha)	18.9	24.6	28.2	33.0	37.6	40.6
	mean dbhob (cm)	9.3	10.5	10.9	11.4	11.9	12.2
	vol (m^3/ha)	54	81	105	137	172	202
	dom. height (m)	7	7	8	9	10	11
25	stems/ha	2580	2569	2704	2846	2929	2934
	ba (m^2/ha)	29.3	33.1	35.8	39.7	43.5	46.1
	mean dbhob (cm)	12.0	12.8	13.0	13.3	13.8	14.1
	vol (m^3/ha)	109	140	169	208	250	288
	dom. height (m)	8	9	10	11	12	13
30	stems/ha	2430	2382	2469	2558	2592	2556
	ba (m^2/ha)	36.0	39.1	41.3	44.6	48.0	50.3
	mean dbhob (cm)	13.7	14.5	14.6	14.9	15.4	15.8
	vol (m^3/ha)	162	200	235	281	330	376
	dom. height (m)	10	11	12	14	15	16
35	stems/ha	2310	2235	2286	2337	2337	2275
	ba (m^2/ha)	41.0	43.7	45.6	48.5	51.5	53.6
	mean dbhob (cm)	15.0	15.8	15.9	16.3	16.8	17.3
	vol (m^3/ha)	216	260	303	355	412	466
	dom. height (m)	11	13	14	16	17	19
40	stems/ha	2211	2115	2138	2161	2137	2056
	ba (m^2/ha)	45.0	47.3	48.9	51.6	54.3	56.1
	mean dbhob (cm)	16.1	16.9	17.1	17.4	18.0	18.6
	vol (m^3/ha)	271	321	370	430	495	555
	dom. height (m)	13	15	16	18	19	21
45	stems/ha	2127	2014	2016	2017	1975	1881
	ba (m^2/ha)	48.2	50.2	51.6	54.0	56.4	58.1
	mean dbhob (cm)	17.0	17.8	18.1	18.5	19.1	19.8
	vol (m^3/ha)	326	382	438	504	576	643
	dom. height (m)	14	16	18	20	22	24
50	stems/ha	2055	1928	1913	1897	1840	1737
	ba (m^2/ha)	50.8	52.6	53.7	55.8	58.0	59.5
	mean dbhob (cm)	17.8	18.6	18.9	19.4	20.0	20.9
	vol (m^3/ha)	380	443	504	577	655	728
	dom. height (m)	16	18	20	22	24	26
55	stems/ha	1992	1854	1824	1794	1726	1616
	ba (m^2/ha)	53.0	54.4	55.3	57.1	59.1	60.3
	mean dbhob (cm)	18.4	19.3	19.7	20.1	20.9	21.8
	vol (m^3/ha)	433	502	568	646	730	808
	dom. height (m)	17	20	22	24	26	28

* Ontario Ministry of Natural Resources, *Forest Res. Rep. No. 108* (Toronto, 1983), p. 38-39

† Stand dominant height (m) at 50 a

VIII. MARKETS AND PRODUCTS

The production of red pine for investment purposes is influenced by a number of factors such as:

- productive capacity of the land,
- intensity of management—thinning and rotation ages,
- accessibility for equipment and to markets,
- labour availability and quality,
- land costs and ownership,
- land value and taxation,
- interest rates now and in the future—economic changes, energy costs.

Love and Williams discuss these items in detail.

Over the past 20 years, the major markets have focussed on red pine plantation for pulpwood and poles. Nonetheless, markets for other products, such as shavings, pallets and small sawlogs have recently increased and become more stable. Currently, there is a strong demand for red pine plantation products. Therefore, management thinning schedules should be satisfactorily met, with a wide range of products being utilized. This trend should continue because of an increase in the future demand for wood in general along with the more marketable size classes and more valuable products that accrue from older plantations. In most areas timber buyers, mills, MNR foresters and consultant foresters keep up-to-date information on timber prices and demand. Table 5 shows relative stumpage values for different products.

Table 6: Pine Product Specifications and Relative Stumpage Values Per Cubic Metre

		Relative value
Pulpwood	– Min. 9 cm top and 2.54 m length	1
Sawlogs/boltwood	– Min. 10 cm top and 2.54 m length	2-3
Loghouse logs	– Min. 20 cm top and 2.5 m – 15 m length	8
Poles	– As per C.S.A. *Standard CAN-015-M83*	5
Piling	– As per C.S.A. *Standard #056-1962*	3

IX. HARVEST CUTTING

Harvest cutting is the removal of a stand of financially or physically mature trees. The harvest can either be a final cut in an even-aged stand or the removal of mature trees from an uneven-aged stand. The major objectives of this cut are to encourage natural regeneration on the site or to prepare the site for artificial regeneration.

The management objectives should determine the rotation age of the stand and the time when the harvest cutting should commence. The rotation age for poles and sawlogs should be set within the biological range of red pine, which is from 60 to 350 years. This rotation age will be dependent upon the changing needs at the time, as well as the stand vigour and growth rate. Red pine planted off-site should be liquidated as soon as possible and the area converted to a species suitable to the site. If the area is to be converted to white pine, the red pine may serve as a nurse crop until the time it is harvested.

Silvicultural systems are named after the method of harvesting and preparing the site for the establishment of a new stand. Three silvicultural systems are recommended for harvesting red pine stands. These are:

(a) uniform shelterwood;
(b) strip shelterwood; and
(c) clearcutting.

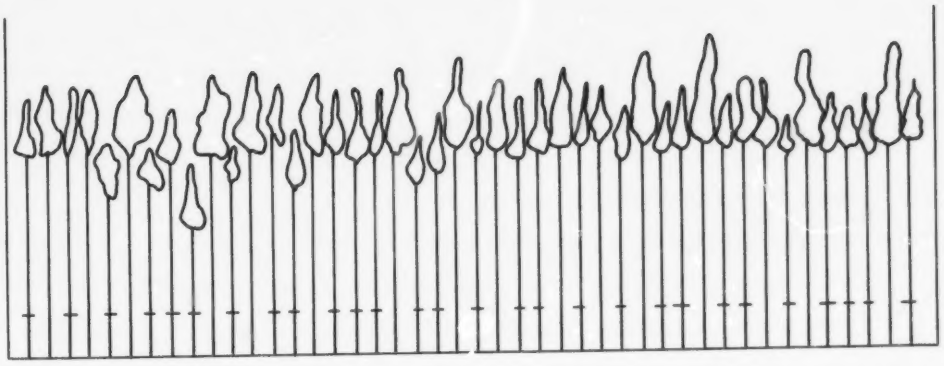
Each of these systems has been used in the management of even-aged red pine stands.

The shelterwood methods provide for regeneration under the shelter of the old stand through partial cuttings resembling thinnings. The first operation, termed preparatory cutting, is aimed at encouraging crown development, increased seed productivity and the improvement of seedbed conditions. This is followed by cuttings which promote the establishment of regeneration from the remaining seed trees. The final cut is the removal of the residual mature trees, and takes place after regeneration is established.

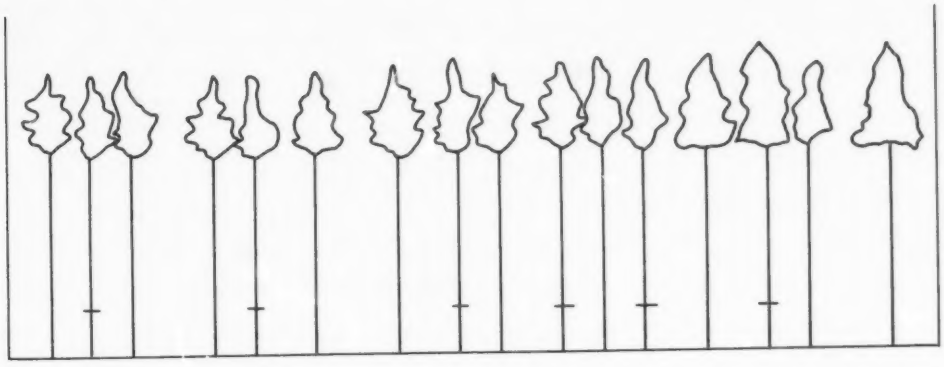
Uniform Shelterwood

The uniform shelterwood system is recommended for regenerating red pine where the soil is coarse to medium sand. To obtain red pine regeneration, 60 to 70 percent of the trees in the stand should be removed. The final cut takes place 10 to 20 years later (Fig. 29).

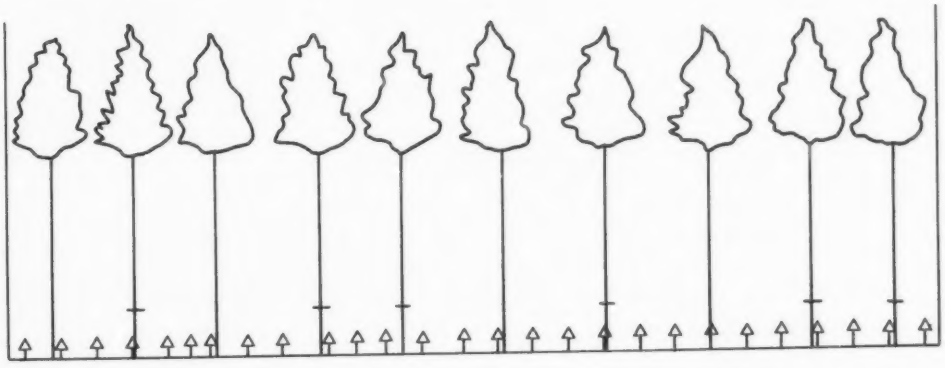
Scarification during a seed year would be helpful and brush control may be necessary to secure establishment of the regeneration. If the soil is deep, fine loamy sand, it may be better to convert the stand to hardwoods. Under these conditions it is recommended that 40 percent of the overstory be removed in the preparatory cutting stage. The final removal of the red pine should take place when desirable regeneration is established.



Pine stand, to be regenerated using the uniform shelterwood system, marked for the preparatory cutting. Trees to be cut are marked by dashes.

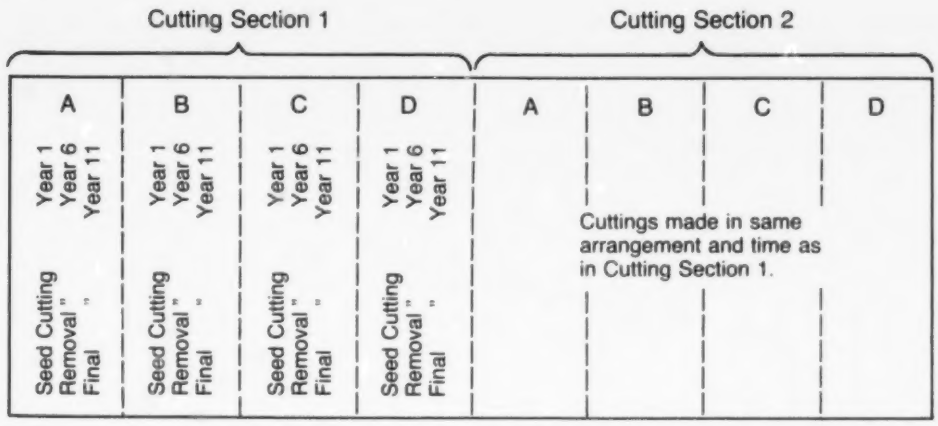


Same stand as above, but several years after the preparatory cutting has been made. The trees to be removed in a seeding cut are marked by dashes.



Same stand as above, but several years after the seeding cut has been made. Note that regeneration has started and is developing under the old stand. Trees to be cut in a first removal cutting are marked with dashes.

Figure 29. *Illustration of uniform shelterwood harvest cutting at three stages in a plantation's life span.*



Regenerating a stand using the strip shelterwood system. The period of regeneration is about 25 years and the stand is kept in even-aged form.

Figure 30. *Illustration shows harvest cutting using the strip shelterwood system which secures natural restocking on cut strips.*

Strip Shelterwood

The strip shelterwood system is another option for establishing pine or hardwoods when harvesting a red pine stand. The shelterwood trees are left in narrow strips, 20 metres or less in width, that can be removed at a later date without damaging the regenerated stand. If advance regeneration is not present, cut strips should be scarified before seedfall in a good seed year (Fig. 30).

The shelterwood systems are used to protect the site and stand quality, protect against inadequate stocking, and reduce the risk of losses to severe storms and adverse weather.

Clear-cutting

Clear-cutting is the most direct method of producing even-aged stands, as this operation removes the entire timber stand from the area (Fig. 32). This system relies upon artificial regeneration or natural seeding from either adjacent stands or cut trees. It is applicable when practically all the trees are merchantable and the one cut is most economical. Clear-cutting provides the cheapest logging and the simplest planning of all harvesting methods.

Clear-cutting followed by artificial regeneration is the easiest of all methods for controlling composition, arrangement and stocking level of the new stand. However, it is the most expensive in terms of initial costs. This method is most applicable to larger clear-cut areas where natural seeding is considered unreliable. Planting should also be considered following a shelterwood cut where natural seeding has not resulted in a satisfactory regeneration within five years.

Figure 31. *A selective harvest in a vigorous red pine plantation. All trees are marked prior to removal and stumps receive a borax treatment. (Douche Tract, Simcoe County Forest)*

Figure 32. *Clear-cutting a jack pine plantation quickly prepared this site for artificial restocking of red pine in 1985. The 46-year-old stand at 1.8 m x 1.8 m spacing yielded about 178 m^3/ha.*

APPENDICES

APPENDIX A

"On-site" Site Class for Red Pine in Site Region 6E*

Texture Group (TG)	Depth to Distinct Mottles						
	>150 cm	100-150 cm	80-100 cm	50-80 cm	30-50 cm	15-30 cm	<15 cm
VGR	(5)‡	3 19.8	(4)	(5)	(5)	(5)	(5)
GSY	5‡ 17.1	3‡ 20.4	3‡ 22.9	(4)	(4)	(5)	(5)
SDY	3 20.6	2 21.9	1 26.1	1/3r 25.0/20.5	2 22.0	3 20.6	4 18.4
GLY	3 19.4	(3)	(2)	(3)	(4)	(4)	(5)
LMY	1/5cr 24.3/16.2	(1)/(5)c	2/5r 22.6/16.7	1/5c 23.3/16.1	3 20.8	3‡ 20.8	(4)
SIY	2 21.4	(3)/(5)r	1 23.1	3/5r 20.8/16.6	2/5r 21.8/15.8	(4)	(5)
FLY	1‡ 23.2	(3)	(3)	3‡ 20.8	4‡ 20.2	5‡ 18.8	(5)
CYY		(5)	(3)	(4)	(5)	(5)	(5)
SHA			2 21.0	(3)	(5)	(5)	(5)

* Site class (SI – 50 a): 1 is > = 23 m
2 is 21 m to 22.9 m
3 is 19 m to 20.9 m
4 is 17 m to 18.9 m
5 is < = 16.9 m

† Brackets around numbers indicate subjective extrapolation of site class – no data collected.
‡ A double dagger indicates that there is insufficient data for proper site-class prediction.
c Indicates site class when free carbonates are within 50 cm.
r Indicates site class when a root-restricting layer occurs within 60 cm (e.g. sandy soil surface overlaying a clay one).

Example: 3/5r Site class: no restrictions / with root-restricting layer.
20.8/16.6 Mean site index: no restrictions / with root-restricting layer.

Table 8: "On-site" Summary for Red Pine Plantations in Site Region 6E

Texture Group (TG)	Statistics*	Depth to Distinct Mottles						
		>150 cm	100-150 cm	80-100 cm	50-80 cm	30-50 cm	15-30 cm	<15 cm
VGR	Site class†	(5)‡	3	(4)	(5)	(5)	(5)	(5)
	Mean		19.8					
	Stddev		1.3					
	Min		18.0					
	Max		21.0					
	Distrib		2(1) 3(7) 4(2)					
	N trees		6					
GSY	Site class	5§	3§	(3)	2	(4)	(4)	(5)
	Mean	17.1	20.4		22.9			
	Stddev	0.8	0.8		0.2			
	Min	16.5	19.5		22.6			
	Max	17.7	21.2		23.0			
	Distrib	4(5) 5(5)	2(2) 3(8)		2(10)			
	N trees	2	4		5			
SDY	Site class	3	2	1	1/3 r	2		4
	Mean	20.6	21.9	26.1	25.0	22.0	20.6	18.4
	Stddev	1.5	1.5	0.6	0.8	1.0	0.2	0.3
	Min	17.4	19.5	22.0	22.8	21.1	20.3	18.0
	Max	24.0	20.5	26.5	25.0	23.0	20.8	18.9
	Distrib	1(1) 2(3) 3(4) 4(2)	1(3) 2(4) 3(3)	1(10)	1(8) 2(2)	1(2) 2(8)	3(10)	4(10)
	N trees	114	30	20	16	15	7	10
GLY	Site class	3	(3)	(2)	(3)	(4)	(4)	(5)
	Mean	19.4						
	Stddev	1.8						
	Min	16.5						
	Max	22.5						
	Distrib	2(1) 3(5) 4(4) 5(1)						
	N trees	13						
LMY	Site class	1 / 5 c r	(1) / (5) c	2 / 5 r	1 / 5 c	3	3§	(4)
	Mean	24.3		22.6	23.3	20.8	20.8	
	Stddev	1.6		1.8	0.5	0.9	0.7	
	Min	21.5		20.5	22.1	19.0	20.0	
	Max	27.0		25.5	24.0	22.0	21.0	
	Distrib	1(7) 2(3)		1(4) 2(3) 3(3)	1(6) 2(4)	2(4) 3(6)	2(2) 3(8)	
	N trees	44		10	7	18	2	
SIV	Site class	2	(3) / (5) r	1	3 / 5 r	2 / 5 r	(4)	(5)
	Mean	21.4		23.1	20.8	21.8		
	Stddev	1.1		0.8	0.3	1.5		
	Min	20.0		22.6	20.5	20.1		
	Max	23.0		23.6	21.0	25.0		
	Distrib	1(1) 2(7) 3(2)		1(6) 2(4)	2(4 3(6)	1(4) 2(3) 3(3)		
	N trees	17		6	6	10		
FLY	Site class	1§	(3)	(3)	3§	4§	5§	(5)
	Mean	23.2			20.8	20.2	18.8	
	Stddev	0.6			0.4	1.1	0.9	
	Min	22.5			20.5	19.4	17.8	
	Max	23.5			21.0	20.7	19.5	
	Distrib	1(7) 2(3)			2(5) 3(5)	3(10)	3(3) 4(7)	
	N trees	3			2	4	3	
CYY	Site class		(5)	(3)	(4)	(5)	(5)	(5)
	Mean							
	Stddev							
	Min							
	Max							
	Distrib							
	N trees							
SHA	Site class			2	(3)	(5)	(5)	(5)
	Mean			21.0				
	Stddev			2.0				
	Min			18.5				
	Max			23.2				
	Distrib			1(1) 2(4) 3(3) 4(2)				
	N trees			8				

* Statistics: mean, standards deviation (StdDev), minimum (Min), maximum (Max), site class distribution (Distrib), number of trees measured (N trees).

Example: 1(8) 2(2) means 80 percent of trees in site 1 and 20 percent of trees in site class 2.

† Site class (SI – 50 a): 1 is ≥ = 23 m
2 is 21 m to 22.9 m
3 is 19 m to 20.9 m
4 is 17 m to 18.9 m
5 is ≤ = 16.9 m

‡ Brackets around numbers indicate subjective extrapolation of site class – no data collected.
§ A section mark indicates that there is insufficient data for proper site-class prediction.
c Indicates site class when free carbonates are within 50 cm.
r Indicates site class when a root-restricting layer occurs within 60 cm.

Example: 1 / 5 r means the site class is 5 if c and/or r conditions are present, otherwise the site class is 1.

Table 9: "On-site" Site Class for Red Pine in Site Region 7E*

Texture Group (TG)	Depth to Distinct Mottles						
	>150 cm	100-150 cm	80-100 cm	50-80 cm	30-50 cm	15-30 cm	<15 cm
VGR	5‡ 18.6	3‡ 21.6	(4)†	(5)	(5)	(5)	(5)
GSY	(5)	(3)	(3)	(3)	(3)	(4)	(5)
SDY	4 19.7	2 24.1	1 25.0	2 24.3	2 23.3	3 21.7	(4)
GLY	5 18.6	(3)	1† 26.0	2 24.4	(3)	(4)	(5)
LMY	2 / 4 c 23.6 / 19.5 c	2† 24.6	2 24.8	2 23.8	3 22.1	3 21.1	(5)
SIY	2 / 4 r 24.2 / 19.7 r	(2) / (4)	2† / 4† r 23.6 / 19.9 r	1 25.2	2† 24.6	3† 21.7	(4)
FLY	2 23.1	(2)	3† 22.2	(3)	3 22.8	3 22.6	(4)
CYY		(3)	(3)	(4)	(5)	5 20.8	(5)
SHA			4† 19.3	4† 20.4	3 22.4	(5)	(5)

* Site class (SI – 50 a): 1 is > = 23 m
2 is 21 m to 22.9 m
3 is 19 m to 20.9 m
4 is 17 m to 18.9 m
5 is < = 16.9 m

† Brackets around numbers indicate subjective extrapolation of site class – no data collected.
‡ A double dagger indicates that there is insufficient data for proper site-class prediction.
c Indicates site class when free carbonates are within 50 cm.
r Indicates site class when a root-restricting layer occurs within 60 cm

Example: 3 / 5 r — Site class: no restrictions / with root-restricting layer.
20.8 / 16.6 — Mean site index: no restrictions / with root-restricting layer.

Table 10: "On-site" Summary for Red Pine Plantations in Site Region 7E

Texture Group (TG)	>Statistics*	Depth to Distinct Mottles >150 cm	100-150 cm	80-100 cm	50-80 cm	30-50 cm	15-30 cm	<15 cm
VGR	Site class†	5‡	3‡	(4)‡	(5)	(5)	(5)	(5)
	Mean	18.6	21.6					
	StdDev	0.3	0.4					
	Min	18.4	21.3					
	Max	18.9	22.3					
	Distrib	5(10)	3(10)					
	N trees	2	2					
GSY	Site class	(5)	(3)	(3)	(3)	(3)	(4)	(5)
	Mean							
	StdDev							
	Min							
	Max							
	Distrib							
	N trees							
SDY	Site class	4	2	1	2	2	3	(5)
	Mean	19.7	24.1	25.0	24.3	23.3	21.7	
	StdDev	1.4	1.4	1.7	1.4	0.5	0.9	
	Min	17.6	23.0	22.9	21.4	21.4	21.0	
	Max	20.4	25.4	26.0	25.7	24.2	22.4	
	Distrib	4(6) 5(4)	1(2) 2(8)	1(8) 2(1) 3(1)	1(3) 2(4) 3(3)	2(5) 3(5)	3 (10)	
	N trees	27	28	13	9	16	12	
GLY	Site class	5	(3)	1‡	2	(3)	(4)	(3)
	Mean	18.6		26.0	24.4			
	StdDev	0.4		–	0.3			
	Min	18.3		–	24.1			
	Max	18.8		–	24.7			
	Distrib	5(10)		–	2(10)			
	N trees	5		3	5			
LMY	Site class	2 4c	2‡	2	2	3	3	5
	Mean	23.6 19.5c	24.6	24.8	23.8	22.1	21.1	18.8
	StdDev	1.0	0.2	0.9	0.9	1.4	1.4	1.1
	Min	23.1	24.4	23.6	21.4	21.3	19.0	18.8
	Max	27.5	24.7	26.0	27.2	24.5	22.3	20.9
	Distrib	1(4) 2(6)	1(10)	1(4) 2(6)	1(3) 2(5) 3(2)	2(4) 3(6)	3(4) 4(6)	4(4) 5(6)
	N trees	40	2	6	17	20	12	9
SIY	Site class	2 4r	(2) (4)	2‡ 4r	1	2‡	3‡	(4)
	Mean	24.2 19.7c		23.6 19.9	25.2	24.6	21.7	
	StdDev	0.5		1.4	0.8	1.1	1.2	
	Min	23.5		22.2	24.8	22.1	21.0	
	Max	24.5		25.3	26.0	25.1	23.0	
	Distrib	2(10)		1(1) 2(6) 3(3)	1(9) 2(1)	1(1) 2(8) 3(1)	2(5) 3(5)	
	N trees	6		4	10	6	3	
FLY	Site class	2	(2)	3‡	(3)	3	3	(4)
	Mean	23.1		22.2		22.8	22.6	
	StdDev	1.5		0.5		0.8	1.4	
	Min	20.0		21.7		21.5	21.0	
	Max	24.5		22.5		24.0	24.5	
	Distrib	2(3) 3(5) 4(2)		3(10)		2(3) 3(7)	2(4) 3(6)	
	N trees	8		3		13	7	
CYY	Site class		(3)	(3)	(4)	(5)	5	(5)
	Mean						20.8	
	StdDev						0.6	
	Min						20.1	
	Max						21.2	
	Distrib						3(3) 4(7)	
	N trees						3	
SHA	Site class			4‡	4‡	3	(5)	(5)
	Mean			19.3	20.4	22.4		
	StdDev			0.5	0.6	1.0		
	Min			18.8	19.0	20.3		
	Max			19.8	20.8	23.5		
	Distrib			4(5) 5(5)	4(10)	2(2) 3(4) 4(4)		
	N trees			4	4	9		

* Statistics: mean, standards deviation (StdDev), minimum (Min), maximum (Max), site class distribution (Distrib), number of trees measured (N trees).

Example: 1(8) 2(2) means 80 percent of trees in site class 1 and 20 percent of trees in site class 2.

† Site class (SI – 50 a): 1 is ≥ 23 m
2 is 21 m to 22.9 m
3 is 19 m to 20.9 m
4 is 17 m to 18.9 m
5 is ≤ 16.9 m

‡ Brackets around numbers indicate subjective extrapolation of site class – no data collected.
§ A section mark indicates that there is insufficient data for proper site-class prediction.
c Indicates site class when free carbonates are within 50 cm.
r Indicates site class when a root-restricting layer occurs within 60 cm.

Example: 1 5 r means the site class is 5 if c and or r conditions are present, otherwise the site class is 1.

Table 11: "Map" for Plantation Red Pine in Site Region 6E

Soil Series surface texture	Drainage* Class	Site† Class	Site Class Distribution	N Trees	Avg SI 50	StdDev SI 50	Min SI 50	Max SI 50	N Sites
Alliston sandy loam	IMP	1	1(7) 2(2) 3(1)	33	23.2	1.3	20.3	25.0	6
Alluvial (variable materials)	VAR	1	1(10)	3	24.6	0.5	24.0	25.0	2
Berrien sandy loam	IMP	2¹	1(6) 2(4)	5	22.0	0.4	22.5	23.5	2
Bondhead (c) sandy loam	W	2	1(1) 2(6) 3(3)	11	21.1	1.7	18.1	23.0	3
Bookton sandy loam	W	1	1(7) 2(3)	9	23.6	1.4	21.8	25.0	3
Brady sandy loam	IMP	2	2(7) 3(3)	11	21.8	1.4	20.1	25.5	3
Brant silt loam	W	2¹	2(3) 3(5) 4(2)	4	21.1	1.3	20.0	23.0	2
Brighton sandy loam	R	3	3(8) 4(1) 5(1)	9	19.5	1.3	16.5	21.0	2
Brisbane gravelly loam	IMP	2	1(4) 2(5) 3(1)	10	22.2	0.9	20.5	23.0	4
Brookston clay loam	P	2¹	2(10)	4	22.5		22.5	22.5	1
Burford (c) gravelly loam	W	2	1(6) 2(2) 3(2)	15	21.9	1.9	18.0	24.0	3
Caledon (c) sandy loam	W	2	2(7) 3(3)	11	21.3	0.8	20.2	22.5	3
Camilla sandy loam	IMP	1¹	1(10)	4	25.3	0.3	25.0	25.5	1
Colbourne sandy loam	W	3	2(2) 3(6) 4(1) 5(1)	8	19.4	1.9	16.5	22.5	3
Cramahe (c) gravelly sandy loam	R	2	2(8) 3(2)	7	21.0	1.0	19.5	22.0	2
Douro Loam	W	1	1(10)	11	25.1	2.0	23.0	27.8	2
Dummer (c) loam	W	4	3(2) 4(4) 5(4)	8	18.3	1.0	16.0	19.0	3
Dundonald sandy loam	W	3	2(8) 3(2)	12	20.7	0.5	20.0	21.4	2
Edenvale (c) sandy loam	IMP	2	1(7) 2(2) 3(1)	9	22.9	1.5	20.0	24.2	3
Embro silt loam	IMP	4¹	4(10)	4	17.7	0.4	17.2	18.0	1
Emily (c) loam	IMP	3¹	3(8) 4(2)	4	19.3	1.3	17.5	20.5	1
Fox sand	W	3	1(2) 2(3) 3(5)	30	20.8	1.4	18.0	23.2	7
Granby sand	P	4	3(3) 4(5) 5(2)	19	17.7	1.1	16.0	19.5	3
Guelph (c) loam	W	1	1(10)	10	26.1	1.2	23.0	24.0	3
Guenn loam	IMP	1	1(10)	7	23.6	0.5	23.0	24.0	2
Hillsburgh fine sandy loam	R	2	1(3) 2(3) 3(4)	24	21.7	1.6	19.5	25.0	5
Honeywood silt loam	W	1	1(8) 2(2)	9	23.7	0.8	22.5	24.7	2
Kemble silty clay loam	IMP	4¹	3(6) 4(4)	3	18.8	0.9	17.8	19.5	1
Listowel loam	IMP	3¹	3(5) 4(5)	4	19.0	0.5	18.5	19.5	1
London loam	IMP	2¹	2(10)	3	22.8	0.3	22.5	23.0	1

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Table 11: "Map" for Plantation Red Pine in Site Region 6E (cont.)

Soil Series surface texture	Drainage* Class	Site† Class	Site Class Distribution	N Trees	Avg SI 50	StdDev SI 50	Min SI 50	Max SI 50	N Sites
Murray silt loam	W	4‡	3(3) 4(7)	3	18.9	0.5	18.3	19.2	1
Newcastle silt loam	W	2‡	1(5) 2(5)	6	22.4	0.7	21.5	23.0	1
Norham silt loam	W	3‡	3(10)	2	20.2	0.2	20.0	20.3	1
Otonabee (c) loam	W	3	1(1) 2(1) 3(7) 4(1)	20	20.0	1.5	18.0	23.5	1
Parkhill (c) loam	P	3‡	3(10)	3	19.3	0.6	19.0	20.0	1
Percy fine sandy loam	R	3	3(7) 4(3)	14	19.2	1.1	17.0	20.5	5
Perth clay loam	IMP	3	2(5) 3(5)	10	20.7	1.1	19.2	22.0	2
Plainfield sand	R	3	3(5) 4(5)	10	19.0	0.9	18.0	20.3	2
Sargent loam	W	4	3(6) 4(3) 5(1)	11	18.9	1.4	16.5	20.5	2
St. Jacobs loam	W	3	2(3) 3(7)	8	20.8	1.1	19.5	22.0	2
Tioga sand	R	2	1(4) 2(3) 3(1) 4(2) 5(2)	29	21.4	2.3	18.0	25.0	8
Trent fine sandy loam	IMP	1‡	1(10)	5	26.0	0.4	25.5	26.5	1
Tuscola silt loam	IMP	2	1(4) 2(4) 3(2)	24	22.6	1.2	20.0	25.0	5
Tweed sandy loam	R	2	1(5) 3(3) 4(2)	8	22.1	3.4	18.0	26.0	3
Vasey sandy loam	W	2	1(1) 2(7) 3(2)	9	21.9	1.3	19.5	23.8	3
Waterloo (c) fine sandy loam	W	3‡	2(4) 3(4) 4(2)	5	20.1	1.4	18.5	22.0	1
Wauseon sandy loam	P	3‡	2(5) 3(5)	2	20.8	0.3	20.5	21.0	1
Wendigo sand	R	2	1(2) 2(6) 3(2)	19	22.1	1.5	20.0	25.0	5

* Drainage class: rapidly drained (R), well-drained (W), moderately well-drained (MW), imperfectly drained (IMP), poorly drained (P), variable drainage (VAR).

† Site class (SI – 50 a): 1 is = 23 m
2 is 21 m to 22.9 m
3 is 19 m to 20.9 m
4 is 17 m to 18.9 m
5 is = 16.9 m

‡ Indicates site class prediction with less than five trees sampled.
(c) Where soils are often calcareous within 50 cm, the site class prediction drops to 5.

Table 12: "Map" for Plantation Red Pine in Site Region 7E

Soil Series surface texture	Drainage* Class	Site† Class	Site Class Distribution	N Trees	Avg SI 50	StdDev SI 50	Min SI 50	Max SI 50	N Sites
Bennington silt loam	W	2¹	1(2) 2(5) 3(3)	4	23.6	1.3	22.2	25.3	2
Beverly silty clay	IMP	3	2(3) 3(4) 4(3)	12	22.1	1.6	19.8	24.5	4
Brady sandy loam	IMP	2	1(3) 2(6) 3(1)	35	24.5	1.5	21.2	27.7	7
Brant loam	W	2¹	2(7) 3(3)	3	23.4	0.9	22.3	24.0	1
Brantford silty clay loam	MW	2	2(7) 3(3)	8	23.1	1.4	20.0	24.5	2
Brisbane (c) gravelly loam	IMP	2¹	1(10)	2	24.9	1.1	21.0	27.5	1
Burford (c) gravelly loam	W	4	2(2) 3(3) 4(2) 5(3)	16	20.6	1.9	19.0	23.5	5
Caledon sandy loam	W	2	1(7) 2(2) 3(1)	6	24.9	1.3	22.9	26.0	3
Crombie silt loam	P	3¹	3(10)	3	21.9	0.2	21.8	22.2	3
Dumfries (c) loam	W	3	2(3) 3(6) 4(1)	35	22.7	1.2	20.0	24.5	4
Embro silt loam	IMP	2	1(4) 2(4) 3(2)	13	24.2	1.4	21.0	25.5	4
Farmington loam	W	4	4(7) 5(3)	8	19.8	0.9	18.8	20.8	3
Fox sand	W	3	1(1) 2(6) 3(1) 4(2)	33	22.6	2.7	17.6	25.4	7
Granby sand	P	3	3(10)	5	22.0	0.5	21.3	22.5	2
Guelph (c) loam	W	3	1(1) 2(4) 3(5)	10	22.9	1.4	21.2	25.5	3
Hillsburgh fine sandy loam	R	5¹	4(3) 5(7)	3	18.8	0.9	18.3	19.8	1
Honeywood silt loam	W	1¹	1(10)	2	26.0	2.1	25.5	27.5	1
Huron clay loam	MW	4¹	4(10)	2	19.3	0.3	19.0	19.5	1
London (c) loam	IMP	2	1(5) 2(5)	8	24.6	0.7	23.5	25.6	3
Normandale loamy very fine sand	IMP	2	1(3) 2(5) 3(2)	6	24.0	1.6	21.5	25.7	3
Oshtemo sand	W	3¹	2(10)	2	22.5	0.7	23.0	24.0	2
Parkhill (c) loam	P	4	3(2) 4(7) 5(1)	12	20.1	0.8	18.8	21.5	3
Perth loam	IMP	3¹	3(10)	3	22.3	0.4	21.7	25.5	1
Plainfield sand	R	3	2(4) 3(4) 4(2)	29	22.0	1.2	19.5	23.8	8
Silver Hill sandy loam	P	3¹	2(5) 3(3) 4(2)	4	22.5	1.2	20.8	23.6	1
St. Jacobs loam	W	3	2(3) 3(7)	7	22.5	1.0	21.3	24.0	1
St. William's sandy loam	P	2¹	2(7) 3(3)	3	23.2	1.3	21.7	24.1	1
Tavistock silt loam	IMP	1	1(6) 2(4)	7	25.0	0.5	24.2	26.0	2
Thorndale silt loam	W	2	2(10)	6	24.2	0.5	23.5	24.5	1
Tuscola silt loam	IMP	2	1(1) 2(3) 3(6)	40	23.0	1.5	21.0	27.5	8
Walsingham sand	IMP	2	1(2) 2(2) 3(6)	17	23.2	1.6	21.0	26.0	5

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Table 12: "Map" for Plantation Red Pine in Site Region 7E (cont.)

Soil Series surface texture	Drainage* Class	Site† Class	Site Class Distribution	N Trees	Avg SI 50	StdDev SI 50	Min SI 50	Max SI 50	N Sites
Waterin sand	P	3‡	3(10)	4	21.7	0.5	21.2	22.4	1
Wattford loamy very fine sand	W	2	2(5) 3(5)	6	23.3	0.9	22.7	24.7	2
Wilsonville loam	R	2‡	1(2) 2(8)	5	23.7	0.9	23.0	25.0	1

* Drainage class: rapidly drained (R), well-drained (W), moderately well-drained (MW), imperfectly drained (IMP), poorly drained (P), variable drainage (VAR).

† Site class (SI – 50 a): 1 is = 23 m
2 is 21 m to 22.9 m
3 is 19 m to 20.9 m
4 is 17 m to 18.9 m
5 is = 16.9 m

‡ Indicates site class prediction with less than five trees sampled.
(c) Where soils are often calcareous within 50 cm, the site class prediction drops to 5.

APPENDIX B

Table 13: Plantation Spacing Equivalents*

Spacing Interval = 0.1 m						Spacing Interval = 0.25 m		
Average Spacing† (m)	Trees per hectare‡ (mean)	(range)	Average Spacing (m)	Trees per hectare (mean)	(range)	Average Spacing (m)	Trees per hectare (mean)	(range)
1.0 x 1.0	10000	11081 – 9070	3.0 x 3.0	1111	1148 – 1075	1.00 x 1.00	10000	13060 – 7901
1.1 x 1.1	8264	9069 – 7561	3.1 x 3.1	1041	1074 – 1008	1.25 x 1.25	6400	7900 – 5289
1.2 x 1.2	6944	7560 – 6400	3.2 x 3.2	977	1007 – 947	1.50 x 1.50	4444	5288 – 3787
1.3 x 1.3	5917	6399 – 5487	3.3 x 3.3	918	946 – 891	1.75 x 1.75	3265	3786 – 2844
1.4 x 1.4	5102	5486 – 4756	3.4 x 3.4	865	890 – 840	2.00 x 2.00	2500	2843 – 2215
1.5 x 1.5	4444	4755 – 4162	3.5 x 3.5	816	839 – 793	2.25 x 2.25	1975	2214 – 1773
1.6 x 1.6	3906	4161 – 3673	3.6 x 3.6	772	792 – 751	2.50 x 2.50	1600	1772 – 1451
1.7 x 1.7	3460	3672 – 3265	3.7 x 3.7	730	750 – 711	2.75 x 2.75	1322	1450 – 1210
1.8 x 1.8	3086	3264 – 2922	3.8 x 3.8	693	710 – 675	3.00 x 3.00	1111	1209 – 1024
1.9 x 1.9	2770	2921 – 2630	3.9 x 3.9	657	674 – 641	3.25 x 3.25	947	1023 – 878
2.0 x 2.0	2500	2629 – 2380	4.0 x 4.0	625	640 – 610	3.50 x 3.50	816	877 – 761
2.1 x 2.1	2268	2379 – 2163	4.1 x 4.1	595	609 – 581	3.75 x 3.75	711	760 – 666
2.2 x 2.2	2066	2162 – 1975	4.2 x 4.2	567	580 – 554	4.00 x 4.00	625	665 – 588
2.3 x 2.3	1890	1974 – 1811	4.3 x 4.3	541	553 – 528	4.25 x 4.25	554	587 – 522
2.4 x 2.4	1736	1810 – 1666	4.4 x 4.4	517	527 – 505	4.50 x 4.50	494	521 – 467
2.5 x 2.5	1600	1665 – 1538	4.5 x 4.5	494	504 – 483	4.75 x 4.75	443	466 – 421
2.6 x 2.6	1479	1537 – 1424	4.6 x 4.6	473	482 – 462	5.00 x 5.00	400	420 – 381
2.7 x 2.7	1372	1423 – 1322	4.7 x 4.7	453	461 – 443	5.25 x 5.25	363	380 – 346
2.8 x 2.8	1276	1321 – 1231	4.8 x 4.8	434	442 – 425	5.50 x 5.50	331	345 – 316
2.9 x 2.9	1189	1230 – 1149	4.9 x 4.9	416	424 – 408	5.75 x 5.75	302	315 – 290

* Sources: W.M. Stiell and R. Plirvee

† Spacing in m = 10000/trees/ha

‡ $\text{Trees/ha} = \frac{10000}{(\text{Spacing in m})^2}$

Table 14: Yields for Unmanaged Red Pine Plantations—Site Index 15*

Age from Planting	Dominant Height	Average Height	Planted Spacing	Trees Per ha	Mean dbh	Basal Area/ha	Volume/ha		Biomass/ha		
							Total	Merchantable	Total Tree	Total Stem and Bark	Merchantable Stem and Bark
(a)	(m)	(m)	(m)		(cm)	(m^2)	(m^3)	(m^3)	(t)	(t)	(t)
20	7.0	5.9	1.25	6335	7.4	27.4	81	14	97	32	5
			1.50	4420	8.5	25.1	71	18	76	28	7
			1.75	3255	9.5	23.2	63	21	62	25	8
			2.00	2498	10.5	21.7	56	22	53	22	9
			2.50	1600	12.4	19.4	45	22	42	18	9
			3.00	1111	14.3	17.7	38	20	36	15	8
			3.50	816	16.0	16.4	32	17	31	13	7
			4.00	625	17.7	15.4	27	15	28	11	6
25	8.5	7.4	1.25	6250	8.2	32.9	125	34	112	49	13
			1.50	4380	9.4	30.1	110	40	90	43	15
			1.75	3238	10.5	27.9	100	43	76	39	17
			2.00	2491	11.6	26.1	91	45	66	36	18
			2.50	1600	13.6	23.4	77	45	53	30	17
			3.00	1111	15.6	21.4	67	43	46	26	17
			3.50	816	17.6	19.8	59	40	41	23	15
			4.00	625	19.4	18.5	53	36	37	21	14
30	10.0	8.8	1.25	6100	8.9	38.1	171	63	127	67	25
			1.50	4320	10.2	35.0	154	69	106	61	27
			1.75	3207	11.3	32.4	140	73	90	55	29
			2.00	2475	12.5	30.4	129	74	80	51	29
			2.50	1597	14.7	27.3	112	74	66	44	29
			3.00	1111	16.9	24.9	99	70	58	39	28
			3.50	816	19.0	23.0	89	65	52	35	26
			4.00	625	21.0	21.6	81	61	48	32	24
35	11.3	10.1	1.25	5910	9.6	42.4	213	96	144	84	38
			1.50	4215	10.8	38.9	193	100	120	76	40
			1.75	3165	12.1	36.2	177	103	106	70	41
			2.00	2454	13.3	34.0	164	102	95	65	40
			2.50	1592	15.6	30.5	144	99	80	57	39
			3.00	1110	17.9	27.9	129	97	70	51	38
			3.50	816	20.1	25.8	117	90	64	46	35
			4.00	625	22.2	24.2	107	85	58	42	33
40	12.6	11.4	1.25	5660	10.2	46.3	257	131	160	101	52
			1.50	4110	11.5	42.8	235	134	138	93	53
			1.75	3116	12.8	40.0	217	135	123	85	53
			2.00	2427	14.0	37.5	202	133	111	80	53
			2.50	1584	16.5	33.7	178	130	95	70	51
			3.00	1109	18.8	30.9	161	126	84	63	49
			3.50	816	21.1	28.6	147	119	76	58	47
			4.00	625	23.3	26.7	135	111	70	53	43

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Table 14: Yields for Unmanaged Red Pine Plantations—Site Index 15* (cont.)

Age from Planting	Dominant Height	Average Height	Planted Spacing	Trees Per ha	Mean dbh	Basal Area/ha	Volume/ha		Biomass/ha		
							Total	Merchantable	Total Tree	Total Stem and Bark	Merchantable Stem and Bark
(a)	(m)	(m)	(m)		(cm)	(m^2)	(m^3)	(m^3)	(t)	(t)	(t)
45	13.9	12.7	1.25	5378	10.9	50.2	303	173	178	119	68
			1.50	3965	12.2	46.4	278	172	156	109	68
			1.75	3045	13.5	43.5	258	170	141	102	67
			2.00	2388	14.8	40.9	241	166	129	95	66
			2.50	1572	17.3	36.8	215	163	112	85	65
			3.00	1105	19.7	33.7	194	155	99	76	61
			3.50	816	22.1	31.3	178	148	91	70	58
			4.00	625	24.4	29.2	165	139	84	65	55
50	15.0	13.7	1.25	5100	11.5	53.0	341	208	193	134	82
			1.50	3835	12.8	49.4	316	205	172	124	81
			1.75	2970	14.1	46.3	295	204	156	116	80
			2.00	2350	15.4	43.7	276	199	144	109	78
			2.50	1558	17.9	39.4	247	193	125	97	76
			3.00	1101	20.4	36.1	224	184	112	88	72
			3.50	815	22.9	33.5	206	175	103	81	69
			4.00	625	25.3	31.3	191	164	95	75	64
55	16.1	14.8	(1.25	4820	12.1	55.7	381	244	208	150	96)
			1.50	3690	13.4	52.0	354	237	189	139	93
			1.75	2888	14.7	49.0	332	236	173	131	93
			2.00	2305	16.0	46.3	312	231	160	123	91
			2.50	1542	18.6	41.8	279	223	141	110	88
			3.00	1096	21.1	38.4	255	212	127	100	83
			3.50	814	23.6	35.7	235	202	116	93	80
			4.00	625	26.1	33.4	219	191	108	86	75
60	17.0	15.7	1.25	4570	12.7	57.7	413	273	223	163	108
			1.50	3560	13.9	54.1	386	266	203	152	105
			1.75	2808	15.2	51.0	362	264	187	143	104
			2.00	2260	16.5	48.4	342	260	174	135	103
			2.50	1526	19.1	43.8	308	249	154	121	98
			3.00	1091	21.7	40.3	281	236	140	111	93
			3.50	812	24.2	37.4	260	226	128	102	89
			4.00	625	25.3	31.3	191	164	95	75	64

* Source: Berry, A.B., 1984.

Table 15: Yields for Unmanaged Red Pine Plantations—Site Index 18*

Age from Planting	Dominant Height	Average Height	Planted Spacing	Trees per ha	Mean dbh	Basal Area/ha	Volume/ha		Biomass/ha		
							Total	Merchantable	Total Tree	Total Stem and Bark	Merchantable Stem and Bark
(a)	(m)	(m)	(m)		(cm)	(m^2)	(m^3)	(m^3)	(t)	(t)	(t)
20	8.4	7.3	1.25	6260	8.1	32.6	122	33	111	48	13
			1.50	4383	9.3	29.8	108	38	89	43	15
			1.75	3240	10.4	27.6	97	42	75	38	16
			2.00	2492	11.5	25.9	89	44	66	35	17
			2.50	1600	13.6	23.1	75	44	53	30	17
			3.00	1111	15.6	21.1	65	42	46	26	17
			3.50	816	17.5	19.5	57	38	40	22	15
			4.00	625	19.3	18.3	51	35	37	20	14
25	10.2	9.0	1.25	6083	9.0	38.8	177	67	131	70	27
			1.50	4314	10.3	35.6	160	74	109	63	29
			1.75	3200	11.5	33.0	145	77	94	57	30
			2.00	2472	12.6	31.0	134	78	83	53	31
			2.50	1596	14.9	27.8	117	77	69	46	30
			3.00	1111	17.0	25.4	104	75	60	41	30
			3.50	816	19.1	23.5	93	69	54	37	27
			4.00	625	21.2	22.0	85	65	50	33	25
30	12.0	10.8	1.25	5780	9.9	44.5	236	116	153	93	46
			1.50	4160	11.2	41.0	215	118	130	85	47
			1.75	3143	12.5	38.3	199	121	116	78	48
			2.00	2441	13.7	36.0	185	118	104	73	47
			2.50	1588	16.1	32.3	162	115	88	64	45
			3.00	1110	18.4	29.5	146	111	80	58	44
			3.50	816	20.6	27.3	133	105	70	52	41
			4.00	625	22.8	25.5	122	99	65	48	39
35	13.6	12.4	1.25	5450	10.7	49.3	292	164	175	115	64
			1.50	4008	12.0	45.6	268	163	152	106	65
			1.75	3065	13.3	42.6	248	161	137	98	64
			2.00	2400	14.6	40.1	232	160	125	91	63
			2.50	1576	17.1	36.1	206	155	108	81	61
			3.00	1106	19.5	33.0	186	149	96	73	58
			3.50	816	21.9	30.6	171	140	88	67	55
			4.00	625	24.2	28.7	158	133	81	62	52
40	15.2	13.9	1.25	5050	11.6	53.4	348	212	197	137	84
			1.50	3810	12.9	49.8	323	210	176	127	83
			1.75	2958	14.2	46.8	301	208	160	119	82
			2.00	2343	15.5	44.1	282	203	148	111	80
			2.50	1556	18.0	39.8	252	197	128	99	77
			3.00	1100	20.6	36.5	229	188	116	90	74
			3.50	815	23.0	33.9	211	179	105	83	71
			4.00	625	25.4	31.7	196	169	98	77	66

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Table 15: Yields for Unmanaged Red Pine Plantations—Site Index 18* (cont.)

Age from Planting	Dominant Height	Average Height	Planted Spacing	Trees per ha	Mean dbh	Basal Area/ha	Volume/ha		Biomass/ha		
							Total	Merchantable	Total Tree	Total Stem and Bar	Merchantable Stem and Bark
(a)	(m)	(m)	(m)		(cm)	(m^2)	(m^3)	(m^3)	(t)	(t)	(t)
45	16.6	15.3	(1.25	4690	12.4	56.8	399	259	218	157	102)
			1.50	3610	13.7	53.3	372	253	198	147	100
			1.75	2845	15.0	50.2	349	251	182	137	99
			2.00	2283	16.3	47.5	329	247	169	130	97
			2.50	1534	18.9	43.0	295	236	149	116	93
			3.00	1093	21.5	39.5	269	226	135	106	89
			3.50	813	24.0	36.7	248	213	124	98	84
			4.00	625	26.4	34.3	231	201	114	91	79
50	18.0	16.7	(1.25	4290	13.3	59.7	448	305	239	176	120)
			1.50	3390	14.5	56.3	421	299	219	166	118
			1.75	2720	15.8	53.3	397	298	205	156	117
			2.00	2205	17.1	50.6	376	290	192	148	114
			2.50	1506	19.7	45.9	339	280	170	134	110
			3.00	1083	22.3	42.3	311	264	154	122	104
			3.50	809	24.9	39.3	288	251	142	113	98
			4.00	624	27.4	36.9	269	237	132	106	93
55	19.3	17.9	(1.25	3910	14.2	62.0	495	351	257	195	138)
			1.50	3170	15.4	58.8	467	346	241	184	136
			1.75	2590	16.6	56.0	444	342	226	175	135
			2.00	2125	17.9	53.3	421	333	213	166	131
			2.50	1474	20.5	48.7	382	317	190	150	124
			3.00	1070	23.1	44.9	351	302	173	138	119
			3.50	805	25.7	41.8	326	287	160	128	113
			4.00	624	28.3	39.2	305	271	150	120	107
60	20.4	19.0	(1.25	3630	15.0	63.9	534	390	276	210	153)
			1.50	2990	16.1	60.9	507	385	259	200	152
			1.75	2475	17.3	58.1	483	382	245	190	150
			2.00	2055	18.5	55.4	459	372	230	181	147
			2.50	1445	21.2	50.8	419	356	209	165	140
			3.00	1058	23.8	47.0	387	337	191	152	132
			3.50	800	26.4	43.8	359	320	177	141	125
			4.00	622	29.0	41.1	337	303	165	133	120

* Source: Berry, A.B., 1984

Table 16: Yields for Unmanaged Red Pine Plantations—Site Index 21*

Age from Planting	Dominant Height	Average Height	Planted Spacing	Trees per ha	Mean dbh	Basal Area/ha	Volume/ha		Biomass/ha		
							Total	Merchantable	Total Tree	Total Stem and Bark	Merchantable Stem and Bark
(a)	(m)	(m)	(m)		(cm)	(m²)	(m³)	(m³)	(t)	(t)	(t)
20	9.8	8.7	1.25	6130	8.8	37.4	164	59	127	65	23
			1.50	4330	10.0	34.3	148	65	104	58	26
			1.75	3210	11.2	31.8	134	68	90	53	27
			2.00	2478	12.4	29.8	124	69	80	49	27
			2.50	1598	14.6	26.8	107	70	66	42	27
			3.00	1111	16.7	24.4	95	66	57	37	26
			3.50	816	18.8	22.6	85	62	51	33	24
			4.00	625	20.8	21.1	77	58	47	30	22
25	11.9	10.7	1.25	5800	9.9	44.3	233	114	154	92	45
			1.50	4165	11.2	41.0	212	117	131	83	46
			1.75	3145	12.4	38.0	196	118	115	77	46
			2.00	2442	13.6	35.7	182	116	103	72	46
			2.50	1589	16.0	32.0	160	114	87	63	45
			3.00	1110	18.3	29.3	143	109	77	56	43
			3.50	816	20.6	27.1	130	103	70	51	40
			4.00	625	22.7	25.4	120	96	64	47	38
30	14.0	12.8	1.25	5360	10.9	50.3	306	174	181	121	69
			1.50	3960	12.3	46.7	281	174	161	111	69
			1.75	3040	13.5	43.8	262	176	143	103	69
			2.00	2387	14.8	41.1	244	171	131	96	67
			2.50	1571	17.3	37.1	217	165	113	85	65
			3.00	1105	19.8	33.9	197	158	101	78	62
			3.50	815	22.2	31.5	180	149	92	71	59
			4.00	625	24.5	29.4	167	140	85	66	55
35	15.9	14.6	(1.25	4860	12.0	55.2	374	236	208	147	93)
			1.50	3710	13.3	51.6	347	232	188	137	92
			1.75	2900	14.6	48.4	324	230	172	128	91
			2.00	2310	15.9	45.8	305	226	159	120	89
			2.50	1545	18.5	41.5	274	216	139	108	85
			3.00	1097	21.0	38.0	249	207	125	98	81
			3.50	814	23.5	35.3	229	197	114	90	77
			4.00	625	25.9	33.0	213	185	106	84	73
40	17.7	16.4	(1.25	4370	13.1	59.2	439	299	235	173	118)
			1.50	3440	14.4	55.8	411	292	218	162	115
			1.75	2745	15.6	52.6	387	286	200	152	112
			2.00	2225	16.9	49.9	366	282	187	144	111
			2.50	1513	19.5	45.4	330	271	165	130	107
			3.00	1086	22.1	41.8	302	257	150	119	101
			3.50	810	24.7	38.8	279	243	138	110	96
			4.00	624	27.2	36.4	261	230	128	103	91

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Table 16: Yields for Unmanaged Red Pine Plantations—Site Index 21* (cont.)

Age from Planting	Dominant Height	Average Height	Planted Spacing	Trees per ha	Mean dbh	Basal Area/ha	Volume/ha		Biomass/ha		
							Total	Merchantable	Total Tree	Total Stem and Bark	Merchantable Stem and Bark
(a)	(m)	(m)	(m)		(cm)	(m^2)	(m^3)	(m^3)	(t)	(t)	(t)
45	19.4	18.0	(1.25	3880	14.3	62.1	497	358	261	196	141)
			1.50	3160	15.4	59.1	472	349	242	186	138
			1.75	2580	16.6	56.2	447	344	227	176	136
			2.00	2120	17.9	53.5	425	340	214	167	134
			2.50	1473	20.5	48.8	385	323	191	152	128
			3.00	1069	23.2	45.1	354	304	176	139	120
			3.50	805	25.8	42.0	329	290	162	130	114
			4.00	623	28.4	39.4	308	274	151	121	108
50	21.0	19.6	(1.25	3470	15.4	64.8	555	411	285	219	162)
			1.50	2895	16.5	61.9	529	402	270	208	158
			1.75	2409	17.7	59.1	504	398	256	198	156
			2.00	2015	18.9	56.5	481	394	242	189	155
			2.50	1428	21.5	51.9	440	374	219	173	147
			3.00	1051	24.1	48.1	407	358	201	160	141
			3.50	797	26.8	44.9	378	336	187	149	133
			4.00	621	29.4	42.2	355	320	174	140	126
55	22.5	21.1	(1.25	3070	16.6	66.7	607	461	308	239	182)
			1.50	2650	17.6	64.3	584	456	297	230	179
			1.75	2243	18.7	61.7	559	453	282	220	178
			2.00	1910	19.9	59.2	535	444	270	211	175
			2.50	1381	22.4	54.6	492	423	245	194	167
			3.00	1031	25.0	50.8	457	402	226	180	158
			3.50	788	27.7	47.5	426	383	211	168	151
			4.00	618	30.3	44.7	401	361	197	158	142
60	23.8	22.3	(1.25	2750	17.7	68.0	649	506	326	256	200)
			(1.50	2440	18.6	66.1	630	504	318	248	198)
			1.75	2085	19.7	63.5	604	495	303	238	195
			2.00	1810	20.8	61.3	583	490	292	230	193
			2.50	1338	23.3	56.8	539	469	269	212	184
			3.00	1010	25.8	52.9	501	446	247	197	175
			3.50	778	28.5	49.6	469	422	231	185	167
			4.00	614	31.1	46.7	441	401	217	174	158

* Source: Berry, A.B., 1984

Table 17: Yields for Unmanaged Red Pine Plantations—Site Index 24*

Age from Planting	Dominant Height	Average Height	Planted Spacing	Trees per ha	Mean dbh	Basal Area/ha	Volume/ha		Biomass/ha		
							Total	Merchantable	Total Tree	Total Stem and Bark	Merchantable Stem and Bark
(a)	(m)	(m)	(m)		(cm)	(m^2)	(m^3)	(m^3)	(t)	(t)	(t)
20	11.1	9.9	1.25	5940	9.5	41.7	206	91	141	81	36
			1.50	4242	10.7	38.3	187	95	120	74	38
			1.75	3177	12.0	35.7	172	98	105	68	39
			2.00	2459	13.2	33.4	159	97	94	63	38
			2.50	1594	15.5	30.1	139	96	79	55	38
			3.00	1110	17.7	27.4	124	92	69	49	36
			3.50	816	19.9	25.4	113	87	62	45	35
			4.00	625	22.0	23.8	103	80	57	41	32
25	13.6	12.4	1.25	5450	10.7	49.3	292	164	176	115	64
			1.50	4008	12.0	45.6	268	163	154	106	65
			1.75	3065	13.3	42.6	248	161	138	98	64
			2.00	2400	14.6	40.1	232	160	126	91	63
			2.50	1576	17.1	36.1	206	155	108	81	61
			3.00	1106	19.5	33.0	186	149	96	73	58
			3.50	816	21.9	30.6	171	140	88	67	55
			4.00	625	24.2	28.7	158	133	81	62	52
30	15.9	14.6	1.25	4860	12.0	55.2	374	236	208	147	93
			1.50	3710	13.3	51.6	347	232	188	137	92
			1.75	2900	14.6	48.4	324	230	172	128	91
			2.00	2310	15.9	45.8	305	226	159	120	89
			2.50	1545	18.5	41.5	274	216	139	108	85
			3.00	1097	21.0	38.0	249	207	125	98	81
			3.50	814	23.5	35.3	229	197	114	90	77
			4.00	625	25.9	33.0	213	185	106	84	73
35	18.1	16.8	(1.25	4250	13.4	60.0	453	308	243	178	121)
			1.50	3370	14.6	56.5	425	306	223	167	120
			1.75	2710	15.9	53.5	401	301	209	158	118
			2.00	2200	17.1	50.8	379	292	193	149	115
			2.50	1505	19.8	46.2	343	281	173	135	111
			3.00	1082	22.4	42.5	314	267	157	124	105
			3.50	809	24.9	39.5	291	253	144	115	100
			4.00	624	27.5	37.1	271	238	134	107	94
40	20.2	18.8	(1.25	3680	14.8	63.6	527	385	273	208	152)
			1.50	3020	16.0	60.5	500	375	258	197	148
			1.75	2500	17.1	57.7	476	371	241	187	146
			2.00	2070	18.4	55.0	453	367	229	178	144
			2.50	1452	21.0	50.4	413	347	205	163	137
			3.00	1060	23.7	46.6	380	331	189	150	130
			3.50	801	26.3	43.5	353	314	174	139	124
			4.00	622	28.9	40.8	331	298	163	130	117

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Table 17: Yields for Unmanaged Red Pine Plantations—Site Index 24* (cont.)

Age from Planting	Dominant Height	Average Height	Planted Spacing	Trees per ha	Mean dbh	Basal Area/ha	Volume/ha		Biomass/ha		
							Total	Merchantable	Total Tree	Total Stem and Bark	Merchantable Stem and Bark
(a)	(m)	(m)	(m)		(cm)	(m^2)	(m^3)	(m^3)	(t)	(t)	(t)
45	22.2	20.8	(1.25	3160	16.4	66.4	597	454	307	235	179)
			1.50	2700	17.4	63.9	573	447	293	226	176
			1.75	2280	18.5	61.3	548	444	278	216	175
			2.00	1935	19.7	58.8	525	436	265	207	172
			2.50	1392	22.2	54.1	481	414	240	189	162
			3.00	1035	24.9	50.2	446	392	222	176	155
			3.50	790	27.5	46.9	416	374	206	164	148
			4.00	619	30.1	44.2	391	352	192	154	139
50	24.0	22.5	(1.25	2720	17.9	68.3	657	512	333	259	202)
			(1.50	2410	18.7	66.2	636	509	321	250	200)
			1.75	2076	19.8	63.9	613	503	308	241	198
			2.00	1798	20.9	61.6	590	496	296	232	195
			2.50	1332	23.4	57.1	546	475	272	215	187
			3.00	1008	25.9	53.3	508	452	251	200	178
			3.50	777	28.6	49.9	476	428	235	187	168
			4.00	613	31.3	47.1	448	408	221	176	160
55	25.7	24.2	(1.25	2380	19.3	69.9	715	572	358	282	226)
			(1.50	2135	20.2	68.1	696	571	351	274	225)
			1.75	1880	21.1	65.9	672	564	336	265	223
			2.00	1665	22.1	64.0	652	561	326	257	221
			2.50	1273	24.5	59.8	609	536	304	240	211
			3.00	977	27.0	56.0	569	512	282	224	202
			3.50	762	29.7	52.6	534	486	265	210	191
			4.00	607	32.3	49.7	504	459	249	198	180
60	27.2	25.6	(1.25	2120	20.7	71.2	766	628	384	302	248)
			(1.50	1920	21.5	69.5	747	620	374	294	244)
			1.75	1735	22.3	67.7	727	618	363	286	243
			2.00	1550	23.3	65.8	707	615	353	278	242
			2.50	1211	25.5	61.9	664	584	329	262	231
			3.00	948	28.0	58.2	623	561	310	245	220
			3.50	747	30.6	54.8	587	534	291	231	210
			4.00	599	33.2	51.9	555	505	276	219	199

* Source: Berry, A.B., 1984

Table 18: Yields for Unmanaged Red Pine Plantations—Site Index 27*

Age from Planting	Dominant Height	Average Height	Planted Spacing	Trees per ha	Mean dbh	Basal Area/ha	Volume/ha		Biomass/ha		
							Total	Merchantable	Total Tree	Total Stem and Bark	Merchantable Stem and Bark
(a)	(m)	(m)	(m)		(cm)	(m^2)	(m^3)	(m^3)	(t)	(t)	(t)
20	12.5	11.3	1.25	5680	10.2	46.0	253	129	163	100	51
			1.50	4116	11.5	42.5	231	132	140	91	52
			1.75	3120	12.7	39.7	214	133	123	84	52
			2.00	2430	14.0	37.2	199	129	112	78	51
			2.50	1585	16.4	33.5	176	127	95	69	50
			3.00	1109	18.8	30.6	158	122	84	62	48
			3.50	816	21.0	28.4	144	115	76	57	46
			4.00	625	23.2	26.5	133	109	70	52	43
25	15.3	14.0	1.25	5015	11.7	53.7	352	215	201	139	85
			1.50	3795	13.0	50.1	326	212	180	128	83
			1.75	2950	14.2	47.0	304	210	162	120	83
			2.00	2338	15.5	44.4	285	205	149	112	81
			2.50	1555	18.1	40.0	255	199	130	100	78
			3.00	1100	20.6	36.7	232	190	117	91	75
			3.50	815	23.1	34.1	214	182	107	84	71
			4.00	625	25.5	31.9	198	170	99	78	67
30	17.9	16.6	1.25	4310	13.3	59.6	446	303	241	176	120
			1.50	3405	14.5	56.2	418	297	221	165	117
			1.75	2725	15.7	53.0	393	295	204	155	116
			2.00	2210	17.0	50.3	372	286	190	147	113
			2.50	1508	19.6	45.7	336	276	169	132	108
			3.00	1084	22.2	42.1	308	262	153	121	103
			3.50	809	24.8	39.1	285	248	141	112	97
			4.00	624	27.4	36.7	266	234	132	105	92
35	20.4	19.0	(1.25	3630	15.0	63.9	534	390	279	210	153)
			1.50	2990	16.1	60.9	507	385	261	200	152
			1.75	2475	17.3	58.1	483	382	246	190	150
			2.00	2055	18.5	55.4	459	372	232	181	147
			2.50	1445	21.2	50.8	419	356	210	165	140
			3.00	1058	23.8	47.0	387	337	192	152	132
			3.50	800	26.4	43.8	359	320	177	141	125
			4.00	622	29.0	41.1	337	303	166	133	120
40	22.8	21.3	(1.25	2980	16.9	67.0	616	474	313	243	187)
			1.50	2590	17.8	64.7	594	469	300	234	185
			1.75	2195	19.0	62.1	569	461	287	224	181
			2.00	1885	20.1	59.7	547	454	274	215	178
			2.50	1370	22.6	55.1	503	433	250	198	170
			3.00	1026	25.2	51.3	467	411	231	184	162
			3.50	785	27.9	47.9	436	392	215	172	155
			4.00	617	30.5	45.1	410	369	201	161	145

Cont. on next page

Table 18: Yields for Unmanaged Red Pine Plantations—Site Index 27* (cont.)

Age from Planting	Dominant Height	Average Height	Planted Spacing	Trees per ha	Mean dbh	Basal Area/ha	Volume/ha		Biomass/ha		
							Total	Merchantable	Total Tree	Total Stem and Bark	Merchantable Stem and Bark
(a)	(m)	(m)	(m)		(cm)	(m^2)	(m^3)	(m^3)	(t)	(t)	(t)
45	24.9	23.4	(1.25	2540	18.6	69.3	689	544	347	271	214)
			(1.50	2260	19.5	67.3	668	541	337	263	213)
			1.75	1970	20.5	65.0	645	535	324	254	211
			2.00	1725	21.5	62.8	622	529	311	245	208
			2.50	1300	24.0	58.6	579	504	290	228	198
			3.00	992	26.5	54.7	540	481	268	213	190
			3.50	770	29.2	51.4	507	456	252	200	180
			4.00	610	31.8	48.5	478	435	236	188	171
50	27.0	25.5	(1.25	2145	20.5	71.0	758	614	381	299	242)
			(1.50	1945	21.3	69.2	739	613	372	291	242)
			(1.75	1754	22.1	67.5	720	612	360	284	241)
			(2.00	1562	23.1	65.6	699	608	349	275	239)
			(2.50	1220	25.4	61.7	656	577	328	258	227)
			(3.00	951	27.9	57.9	616	554	308	243	219)
			(3.50	749	30.5	54.6	580	528	289	228	207)
			(4.00	600	33.1	51.6	549	500	272	216	197)
55	28.9	27.3	(1.25	1840	22.3	72.2	821	681	409	323	268)
			(1.50	1700	23.0	70.7	804	675	401	317	266)
			(1.75	1555	23.8	69.1	785	667	392	309	263)
			(2.00	1415	24.7	67.5	767	667	384	302	262)
			(2.50	1140	26.7	64.0	727	640	361	286	252)
			(3.00	909	29.1	60.5	686	617	341	270	243)
			(3.50	728	31.6	57.2	648	590	321	255	232)
			(4.00	589	34.3	54.3	615	560	306	242	220)
60	30.7	29.1	(1.25	1600	24.1	73.1	880	739	439	347	291)
			(1.50	1505	24.7	72.0	866	736	433	341	290)
			(1.75	1410	25.3	70.9	853	734	426	336	289)
			(2.00	1290	26.2	69.3	834	734	417	328	289)
			(2.50	1068	28.1	66.1	794	707	397	313	279)
			(3.00	866	30.4	62.7	753	678	376	297	267)
			(3.50	704	32.8	59.5	715	651	355	282	257)
			(4.00	577	35.4	56.7	681	627	339	268	247)

* Source: Berry, A.B., 1984

Table 19: Age at Which MAI Is at a Maximum

		Spacing (m)					
	SI	1.25	1.50	1.75	2.00	2.50	3.00
Total volume	15	55	55	55			
	18	55	55	55	55		
	21	50	55	55	55		
	24	45	45	50	55	55	
	27	40	40	50	50		
Merchantable volume	15						
	18						
	21						
	24		55			55	
	27	55					
Total biomass	15	20	20	55	55		
	18	20	40	50	55		
	21	20	40	55	55		
	24	20	45	45	55	55	
	27	20	40	45	55		
Biomass of total stem plus bark	15	55					
	18	55	55	55	55		
	21	50	55	55	55		
	24	45	45	50	55		
	27	40	40	50	50		
Biomass of merchantable stem plus bark	15						
	18						
	21						
	24		55				55
	27	55	50	50	50		

APPENDIX C

Table 20: Standard Volumes For Plantation Red Pine*

Total volume (m^3) (stump and top included)

Diameter Class (cm)	Height class (m)									
	8	10	12	14	16	18	20	22	24	26
6	0.006	0.009	0.011							
8	0.015	0.020	0.025	0.030	0.035					
10	0.026	0.034	0.042	0.050	0.058	0.066				
12	0.040	0.052	0.063	0.074	0.086	0.097	0.109			
14	0.057	0.072	0.088	0.103	0.119	0.134	0.149	0.165		
16	0.076	0.096	0.116	0.136	0.156	0.176	0.196	0.216	0.235	
18		0.123	0.148	0.173	0.198	0.223	0.248	0.273	0.298	0.322
20		0.152	0.184	0.214	0.245	0.276	0.306	0.336	0.366	0.396
22			0.222	0.260	0.296	0.333	0.369	0.405	0.441	0.477
24			0.265	0.309	0.352	0.395	0.438	0.480	0.522	0.563
26					0.412	0.461	0.511	0.560	0.608	0.656
28						0.532	0.589	0.644	0.699	0.753
30							0.671	0.733	0.795	0.855
32							0.756	0.826	0.895	0.962
34							0.846	0.923	0.998	1.072
36							0.939	1.023	1.105	1.185
38							1.034	1.125	1.214	1.300
40							1.133	1.230	1.325	1.417
42							1.233	1.337	1.438	1.535

*A.B. Berry, Petawawa National Forestry Institute; based on 720 trees in Ontario, measured by the Ontario Ministry of Natural Resources and the Canadian Forestry Service.

The basic measurements, for individual trees, of height, diameter and volumes were converted from English to Metric units. The diameters were increased by application of the formula:

$Y = 0.0029 + 1.005X \qquad (R^2 = 0.9994)$

where X is the diameter at 4.5 ft.

and Y is the diameter at 1.3 m

since the point of diameter measurement in metric system is at 1.3 m

Individual tabular values obtained from the regression:

$$V = -0.0059 + 0.4015\left(\frac{D^2H}{10000}\right) - 0.01429\left(\frac{D^2H}{10000}\right)^2 \qquad (R^2 = 0.9876)$$

$$(Se_e = 8.52\% \text{ of } \bar{V})$$

where V is total volume in m^3

D is $dbh_{1.3}$ in cm

H is total height in m

APPENDIX D

Table 21: Red Pine Plantation Site Indexes*

Age (a)	Stand dominant height (m) at age 50 — Present height (m)																
	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34
20	13	15	18	21	24	26	29	32	35								
22	11	14	17	19	22	25	27	30	33								
24	10	13	15	18	21	23	26	28	31	33							
26		12	14	17	19	22	24	27	29	32	34						
28		11	13	16	18	20	23	25	28	30	32	35					
30		10	12	15	17	19	22	24	26	29	31	33					
32			11	14	16	18	21	23	25	27	30	32	34				
34			11	13	15	17	20	22	24	26	29	31	33				
36			10	12	14	16	19	21	23	25	27	30	32	34			
38				11	14	16	18	20	22	24	26	29	31	33			
40				11	13	15	17	19	21	23	26	28	30	32	34		
42				10	12	14	16	18	21	23	25	27	29	31	33		
44					12	14	16	18	20	22	24	26	28	30	32	34	
46					11	13	15	17	19	21	23	25	27	29	31	33	
48					10	13	15	17	19	21	23	25	27	29	31	33	35
50					10	12	14	16	18	20	22	24	26	28	30	32	34
52						11	13	15	17	19	21	23	25	27	29	31	33
54						11	13	15	17	19	21	23	25	27	29	31	

*Ontario Ministry of Natural Resources. *Forest Research Report. No. 108.* 1983.

Based on the following site index equation:

site index (m) = a + b H

where a = 33.6154 − 5.5278 ($A^{1/2}$) + 0.002164 (A^2)

b = 0.7455 + 12.7255 (A^{-1})

H = stand dominant height (m)

A = stand age (years)

Standard error 0.6676 m R^2 0.9696

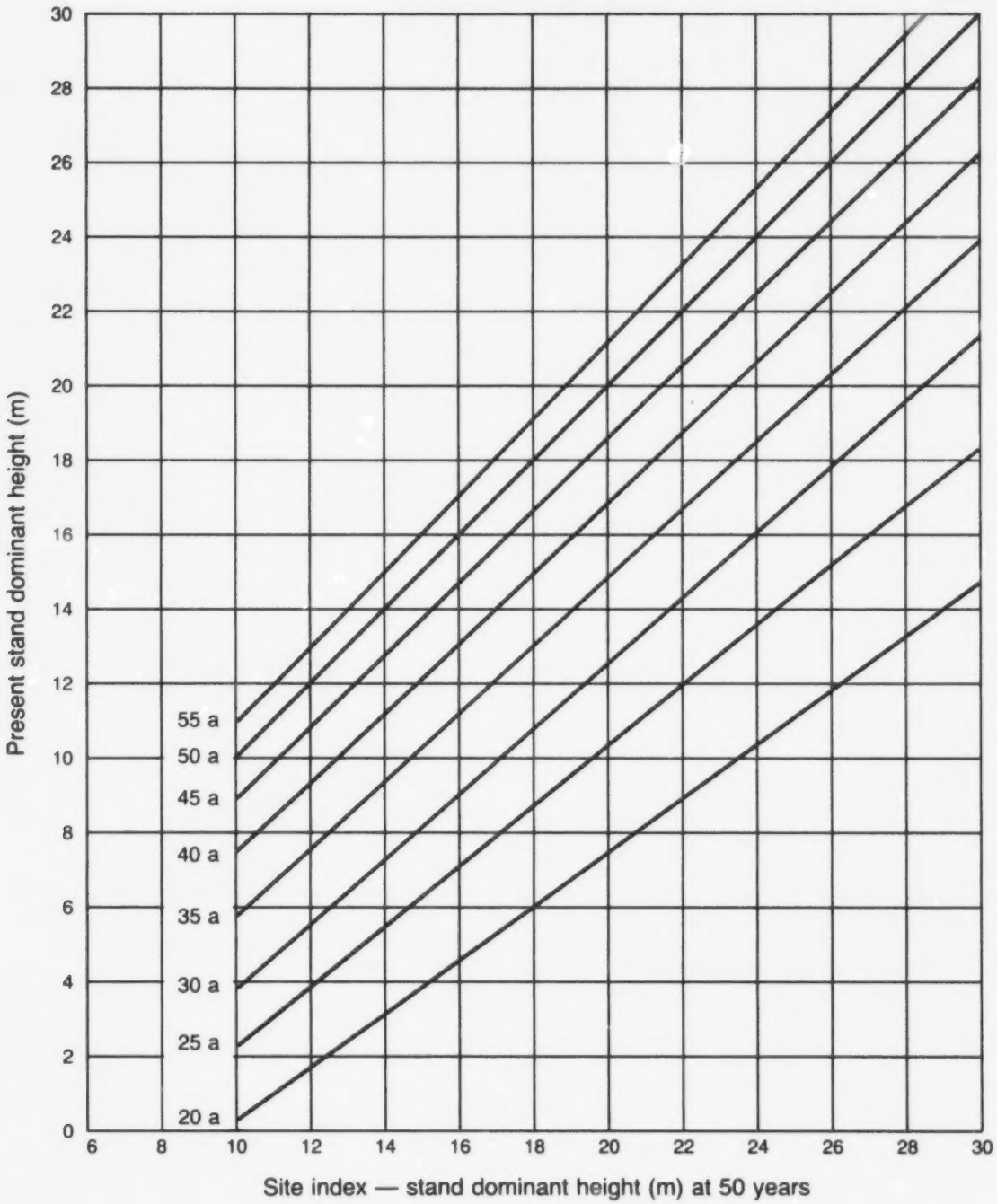

Figure 33. *Red pine plantation site index chart.**

*Ontario Ministry of Natural Resources. *Forest Res. Rep. No. 108.* 1983.

APPENDIX E

Table 22: Pole Utilization from Plantation Red Pine*

Tree dbh (o.b.) Class (cm)	Tree height class (m) 14	16	18	20	22	24
	Longest pole available per class [pole class – length (m)]					
20	7- 6.5	7- 6.5	7- 6.5	7- 6.5	7- 6.5	7- 6.5
22	7- 6.5	7- 8.0 6- 6.5	7- 8.0 6- 6.5	7- 8.0 6- 6.5	7- 8.0 6- 6.5	7- 8.0 6- 6.5
24	7- 8.0 6- 8.0 5- 6.5	7- 9.5 6- 8.0 5- 6.5	7- 9.5 6- 8.0 5- 6.5	7- 9.5 6- 8.0 5- 6.5	7-11.0 6- 8.0 5- 6.5	7-11.0 6- 8.0 5- 6.5 4- 6.5
26		7- 9.5 6- 8.0 5- 8.0	7-11.0 6- 9.5 5- 8.0 4- 6.5	7-12.5 6- 9.5 5- 8.0 4- 6.5	7-12.5 6- 9.5 5- 8.0 4- 6.5 3- 6.5	7-12.5 6- 9.5 5- 8.0 4- 6.5 3- 6.5
28			7-12.5 6-11.0 5- 9.5 4- 8.0 3- 6.5	7-14.0 6-12.5 5- 9.5 4- 8.0 3- 6.5	7-15.5 6-12.5 5- 9.5 4- 8.0 3- 6.5 2- 6.5	7-15.5 6-12.5 5- 9.5 4- 8.0 3- 6.5 2- 6.5
30				7-14.0 6-14.0 5-11.0 4- 9.5 3- 8.0 2- 6.5	7-15.5 6-14.0 5-12.5 4- 9.5 3- 8.0 2- 6.5	7-17.0 6-14.0 5-12.5 4- 9.5 3- 8.0 2- 6.5
32					7-15.5 6-15.5 5-14.0 4-11.0 3- 9.5 2- 8.0 1- 6.5	7-17.0 6-17.0 5-14.0 4-11.0 3- 9.5 2- 8.0 1- 6.5

(Above stump height of 0.3 m.)

* A.B. Berry, Petawawa National Forestry Institute; based on 321 trees in Ontario, measured by the Ontario Ministry of Natural Resources and the Canadian Forestry Service.

APPENDIX F

Table 23: Dimensions of Red Pine Poles (Fibre Stress 42 MPa)*

Pole class		1	2	3	4	5	6	7
Minimum top Diameter (cm)		21.6	20.1	18.5	16.9	15.3	13.7	12.1
Length (m)	Ground line Distance from Butt (m)	Minimum diameter (cm) at 1.80 m from butt						
6.5	1.25	27.7	25.8	23.9	22.3	20.7	19.1	17.5
8.0	1.40	30.2	28.3	26.4	24.5	22.6	21.0	19.4
9.5	1.55	32.5	30.6	28.3	26.4	24.5	22.6	21.0
11.0	1.70	34.7	32.5	30.2	28.0	26.1	24.2	22.3
12.5	1.85	36.6	34.4	31.8	29.6	27.4	25.5	23.6
14.0	2.00	38.5	36.0	33.4	31.2	29.0	26.7	24.8
15.5	2.15	40.1	37.6	35.0	32.5	30.2	27.7	25.8
17.0	2.30	41.7	38.8	36.3	33.7	31.2		
19.0	2.50	43.6	40.7	37.9	35.3			
21.0	2.70	45.2	42.3	39.5	36.6			

* Adapted by A.B. Berry from C.S.A. *Standard CAN3-015-M83*, January, 1983.

APPENDIX G

Table 24: Reinforcing Stub Utilization from Plantation Red Pine*

Tree dbh (o.b.) Class (cm)	Tree Height Class (m)					
	14	16	18	20	22	24
	[Stub Class – Length (m)]					
22		W–3.0	W–3.0	W–3.0	W–3.0	W–3.0
24	W–3.0	W–3.0	W–3.0	W–3.0	W–3.0	W–3.0
26		W–3.5	W–3.5 X–3.0	W–3.5 X–3.0	W–3.5 X–3.0	W–3.5 X–3.0
28			W–4.0 X–3.0	W–4.0 X–3.0	W–4.0 X–3.0	W–4.0 X–3.0
30					W–5.0 X–3.5 Y–3.0	W–5.0 X–3.5 Y–3.0
30					W–6.0 X–4.0 Y–3.0	W–6.0 X–4.0 Y–3.0

(Above stump height of 0.3 m.)

* A.B. Berry, Petawawa National Forestry Institute; based on 321 trees in Ontario, measured by the Ontario Ministry of Natural Resources and the Canadian Forestry Service.

APPENDIX H

Table 25: Dimensions of Red Pine Reinforcing Stubs (Fibre Stress 42 MPa)*

Length (m)	Class Z	Class Y	Class X	Class W
	Minimum diameter (cm) at 1.80 m from butt			
3.0	30.9	26.7	22.9	19.4
3.5	35.0	30.2	25.8	22.0
4.0	38.5	33.4	28.6	24.2
5.0	40.1	34.7	29.6	25.1
6.0	43.6	37.9	32.5	27.7

* Adapted by A.B. Berry from *CSA Standard CAN3-015-M83*, January, 1983.

APPENDIX I

Derivation of Pole and Reinforcing Stub Utilization[1]

(a) Took Canadian Forestry Service (CFS) data and had the basic measurement of height, dbh, and taper measurement converted to SI units by computer (PDP 11). The data were then summarized by two centimetre classes and two metre height classes.

(b) The Ontario Ministry of Natural Resources (OMNR) data dbh, height and volume had been converted previously to SI units and summarized by two centimetre diameter and two metre height classes.

(c) The CFS data were inspected and any diameter and height cell containing less that 10 trees was supplemented by the trees form OMNR data of the same size class.

(d) The OMNR data for each of the selected trees were interpolated to provide inside bark measurements at tenths of height above breast height so that they were compatible with CFS data. The original OMNR stem measurements had been taken at the top of sawlog or pulpwood sections.

(e) Harmonized taper curves were drawn for each two metre height class for those diameter classes that were large enough to produce poles.

(f) From these series of curves, the longest pole that could be produced from each pole class was determined. The minimum top diameter and diameter at 1.8 metres from the butt for each length and class of pole were derived from dimensions of red pine poles produced by Canadian Standard Association. *Standard CAN3-015-M83*, January, 1983.

(g) From the series of curves, the longest reinforcing stub of each class for each combination of height and tree diameter was determined.

[1] A.B. Berry. 1984
Petawawa National Forestry Institute
Canadian Forestry Service

APPENDIX J

Selected Metric Units, Symbols and Uses

UNIT	SYMBOL	MEASUREMENT USE
centimetre	cm	Diameter of single trees; average diameter of trees in stands; diameter of logs, bolts and poles
cubic metre	m^3	Volume of single trees, stands of trees, logs, wood products and liquids
gram	g	Mass (weight) of trees, branches, fertilizers, etc.
kilometre	km	Distance
litre	L	Volume of liquids
metre	m	Height of single trees; distance; average height of stands of trees; length of logs, bolts, poles and lumber
millimetre	mm	Length of panels; width and thickness of lumber
square centimetre	cm^2	Area
square kilometre	km^2	Area
square metre	m^2	Area; basal area of single trees and stands of trees; quadrats
stacked cubic metre	m^3 (stacked)	Volume of stacked wood
tonne	t	Mass (weight) of wood, etc.
hectare	ha	Area

Imperial and Metric Equivalents

IMPERIAL		METRIC
LENGTH		
1 chain	=	20.1168 m
1 foot	=	0.3048 m
1 inch	=	2.54 cm
1 mile	=	1.60934 km
0.393701 inches	=	1 cm
0.621371 miles	=	1 km
0.0497097 chains	=	1 m
3.28084 feet	=	1 m
AREA		
1 acre	=	0.404686 ha
1 mil-acre	=	4.04686 m^2
1 square foot	=	0.092903 m^2
1 square mile	=	2.58999 km^2
2.47105 acres	=	1 ha
0.386102 square miles	=	1 km^2
0.247105 mil-acres	=	1 m^2
10.7639 square feet	=	1 m^2
VOLUME		
1 cord stacked	=	3.62456 m^3 (stacked)
1 cubic foot	=	0.0283168 m^3
1 cubic yard	=	0.764555 m^3
1 cunit	=	2.83168 m^3
1 gallon	=	4.54609 L
0.219969 gallons	=	1 L
35.3147 cubic feet	=	1 m^3
0.353147 cunits	=	1 m^3
0.275896 cords	=	1 m^3 (stacked)
WEIGHT		
1 ounce	=	28.3495 g
1 pound	=	0.453592 kg
1 ton	=	0.907185 t
0.035274 ounces	=	1 g
2.20462 pounds	=	1 kg
1.10231 tons	=	1 t

Imperial and Metric Ratios

IMPERIAL		METRIC
1 cord per acre	=	8.95647 m^3 (stacked)/ha
1 cubic foot per acre	=	0.0699725 m^3/ha
1 pound per cubic foot	=	16.0185 kg/m^3
1 square foot per acre	=	0.229568 m^2/ha
1 ton per acre	=	2.2417 t/ha
0.062428 pounds per cubic foot	=	1 kg/m^3
4.356 square feet per acre	=	1 m^2/ha
14.2913 cubic feet per acre	=	1 m^3/ha
0.111651 cords per acre	=	1 m^3 (stacked)/ha
0.44609 tons per acre	=	1 t/ha

APPENDIX K

Case Histories:
Red Pine Management at Hendrie Forest

The Hendrie Main Tract of Simcoe County Forest was purchased by the County and has been managed by MNR since 1922. On the original purchase of 405 hectares, an estimated 35 900 cubic metres had been removed by 1982, with about 83 300 cubic metres of growing stock remaining in the block. In the 60 years since planting, the total production has averaged about 4.9 cubic metres per hectare per year.

EXAMPLE 1

Red pine thinning trials were set out (1948) in a stand planted in 1924. Thinnings of other intensities were also set out in the Maple District at the same time. Measurements are taken at five-year intervals by forest research staff thus ensuring continuity of investigation. Based on these thinning experiments, it has been determined which maximum thinning will keep branch diametres small, and thus provide pole quality production from intermediate thinnings. Whether this thinning level will also provide maximum volume production has not yet been confirmed.

Plot 15 is an unthinned control. Plot 13, thinned 8 times at 5-year intervals, represents a **moderate** level of thinning for pole production, at SDI 717.

Table 26: Hendrie Forest—Site Index 22.9

	Plot 15 (unthinned)				Plot 13 (thinned 8 times)			
	B.A. (m^2/ha)	Stem/ha	Average dbh (cm)	G.T.V. (m^3)	B.A. (m^2/ha)	Stem/ha	Average dbh (cm)	G.T.V. (m^3)
Present 1983	58.9	1651	21.4	653.9	38.2	588	28.7	452.8
Removed 1948-83	____	____	____	____	44.1	____	____	359.0
Total production	58.9			653.9	82.3			811.8
Average	1.0/a			11.1/a	1.4/a			13.8/a

EXAMPLE 2

There have been five previous thinnings in these stands. North of the road previous thinnings were "from below". Part of the stand was damaged in a 1984 windstorm. South of the road a thinning "from above and below" was carried out in 1973.

Products produced from the current (1983-84) thinnings are as follows:

Table 27: Hendrie Forest—Red Pine Pole Thinning (Comp 205)

	North of road	South of road
Number of red pine trees	21	556
Number of white pine trees	2	26
Total number of trees	23	582
Volume	11 m^3	222 m^3
Average value per tree	$ 3.48	$ 7.73
Average value per cubic metre	$13.64	$20.27

Red Pine Management at Larose Forest

Larose Forest, consisting of some 10 500 hectares, is Ontario's largest contiguous area of forest plantation (it includes a small area of natural forest). The forest is owned by the United Counties of Prescott and Russell and is located near Bourget, some 40 kilometres east of Ottawa. The forest has been managed since 1928 by the Ministry of Natural Resources (formerly the Department of Lands and Forests).

To illustrate the ongoing management of this forest, we have chosen the oldest plantation set out in 1928 (a red and white pine mix) on an area of 9.7 hectares. Over a period of 32 years since the first salvage material was removed, seven thinning cuts have been carried out along with a small salvage treatment in 1962.

Table 28: Larose Forest—Forest Management (Comp 124D)

Compartment 124D—9.7 ha	
Planted 1928—alternate rows of Pw and Pr at spacing of 1.5 m x 1.5 m	
Poor quality, weeviled and blister-rusted trees removed in 1953—48 m^3	
Selective thinning 1958—149 m^3 of pulpwood — 7 m^3 of fuelwood —6805 fbm of logs	
Salvage cut, following an ice storm, 1962—1.4 m^3	
Selective cut 1969—643.4 m^3 pulpwood	
Selective thinning 1973—53.6 m^3 pulpwood —30475 fbm	$1 096.49
Selective thinning 1974—86.2 m^3 pulpwood —10623 fbm logs	$ 576.63
Pole cut 1980—216 poles, 170 m^3	4 021.00
Pole cut 1981—100 poles, 115 m^3	2 000.00
Pole cut 1982—230 poles, 253 m^3 + 44.6 m^3 pulp	8 050.00
Total volume cut = 1571.2 m^3 + 47 903 fbm – Total revenue	$15 744.12
Remaining volume 3055.5 m^3	

Hence, the total average **volume per hectare** produced from Compartment 124D to 1982, inclusive is 161.9 m^3 plus 4 938 fbm
(pulp, poles and fuel) (sawlogs)

Gross revenue (recorded) is $1,623.10/ha

Management at the Rockland Plantation

This 6.2 hectare stand was planted in 1914 at Rockland, about 40 kilometres east of Ottawa. It is the oldest managed red pine plantation in Ontario for which detailed records have been kept. Managed cooperatively by its owners and the Canadian Forestry Service, the main part of the stand has been thinned four times: one permanent plot samples this portion, and one permanent plot samples a small control (untreated portion). These plots have been remeasured many times since their establishment at the time of the first thinning in 1938. The results of this experiment have been the subject of numerous publications, the most recent in 1982.

Comparative growth data for the thinned and unthinned plots are presented in Table 29. The results of treatment are summarized below.

In 1981, the height and diameter of the tree of average basal area were 27.1 metres and 31.2 centimetres respectively, in the thinned stand, and 26.8 metres and 23.9 centimetres in the control. The tallest tree (29.3 metres high) was located in the control.

On the control area a maximum basal area of 53 square metres per hectare was reached at 52 years from planting. Over the next 15 years, natural mortality on that plot exceeded growth for a net loss, and during the last five years natural mortality nearly equalled total volume growth. Since the mortality occurred only in the smallest trees, the five-year growth in pulpwood and sawlog sizes made a small net increase. At the same time, net gain in the thinned plot was three times as large in pulpwood volume and 20 percent in sawlog volume.

An economic analysis of the 1971 data showed that financial maturity at four percent and six percent was highest at age 57 in both thinned and control stands. However net sawlog volume growth continued over the next 10 years increasing the value, although height growth was declining.

Stand conditions in 1981 were poor on the control area, with excessive sweep or lean and short crowns, and mortality continuing at two percent per year. Risk of mass collapse from a fall of wet snow seems high. Still, the merchantable volume even of the untreated portion exceeds by 40 percent that given in Plonski's yield tables for site class 1 natural red pine stands of the same age. This is an excellent sample of the superior productivity made possible in plantations by uniform spacing and high stocking alone.

Table 29: Rockland Plantation—Summary of Growth Data

Age	Year	Number of Trees		Basal area (m^2)		Total Volume (m^3)		Merchantable Volume (m^3)*	
		Thinned	Control	Thinned	Control	Thinned	Control	Thinned	Control
24	1938								
	BT[b]	2253	2412	44.3	46.1	258	267	164	165
	T[c]	795	–	12.2	–	70	–	34	–
	AT[d]	1458	2412	32.1	46.1	188	267	130	165
29	1943								
	BT	1438	2184	36.0	47.7	239	313	178	212
	GPI[e]	–	–	4.1	4.6	53	63	49	48
	M[f]	20	228	0.2	3.0	2	17	1	1
37	1951								
	BT	1398	1982	42.2	48.7	331	376	268	284
	T	400	–	9.1	–	70	–	51	–
	AT	998	1982	33.1	48.7	261	376	217	284
	GPI	–	–	6.9	4.0	97	83	92	83
	M	40	202	0.7	3.0	5	20	2	11
42	1956								
	BT	998	1804	37.0	49.6	323	416	275	329
	GPI	–	–	3.9	3.4	62	59	58	58
	M	0	178	0	2.5	0	19	0	13
47	1961								
	BT	988	1675	41.1	51.2	383	473	329	383
	T	20	–	7.3	–	68	–	57	–
	AT	786	1675	33.8	51.2	315	473	272	383
	GPI	–	–	4.3	3.7	62	74	55	66
	M	10	129	0.2	2.1	2	17	1	12
52	1966								
	BT	786	1557	37.9	53.0	382	517	334	432
	GPI	–	–	4.1	3.9	67	63	62	63
	M	0	118	0	2.1	0	19	0	14
57	1971								
	BT	776	1359	41.3	51.4	435	534	378	459
	T	381	–	16.7	–	173	–	148	–
	AT	395	1359	24.6	51.4	262	534	230	459
	GPI		–	3.6	2.5	56	55	44	56
	M	10	198	0.2	4.1	3	38	2	29
62	1976								
	BT	390	1265	26.9	52.1	300	572	269	486
	GPI	–	–	2.5	3.0	41	60	41	44
	M	5	94	0.2	2.3	3	22	2	17
67	1981								
	BT	390[g]	1137[h]	29.8	50.3	339	573	308	500
	GPI	–	–	2.9	1.4	39	35	39	40
	M	0	128	0	3.2	0	34	0	26

* Trees 15.2 cm DBH and larger, [b]BT – before thinning, [c]T – thinning, [d]AT – after thinning, [e]GPI – gross periodic increment, [f]M – mortality, [g]includes 2 trees cut by vandals, [h]includes 10 trees cut by vandals.

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